Are the tunnel ventilation systems adapted for the different risk situations ?

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Are the tunnel ventilation systems adapted for the different risk situations?

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ABSTRACT

The ventilation design criteria for both road and rail tunnel is based on the design fire defined by the standards and the general knowledge about smoke propagation. The problem of such an approach is that it considers only the impact on the safety ventilation of the smoke propagation and dispersion inside the tunnel excluding other possible accident. However some other situations, such as toxic gas release, are possible and even if the aim is not to design the ventilation on other dangerous phenomena with a lower occurrence frequency, it must be ensure that the ventilation system does not increase the consequences of the accident. Mainly, the problem of toxic gas dispersion is pointed out in this paper.
Because of the large variety of dangerous materials that can transit in tunnel, the probability of an accident that impacts a toxic transport cannot be neglected. In the worst case scenario, such as a massive release of high toxic gases, the ventilation is useless because of the toxic quantity that induces a large number of deaths inside the tunnel. However, when the toxic release is lower and ventilation can be used, having in mind that toxic gas is generally heavy gas or a cold gas, the behaviour will of course be different than the one of smoke and the ventilation system may not be adapted for such a situation. This case has scarcely been studied yet.
In this study, both experimental approach and numerical tools were used to improve the global understanding of dense gas dispersion in underground infrastructure such as road tunnels. The experimental work was achieved in the INERIS fire gallery which represents a 50 m long 1/3rd scale tunnel using Argon. It was achieved for different leaks conditions in order to appreciate the dense gas natural behaviour. This work has also enabled the comparison between experimental work and CFD calculation with FDS code for the particular application of dense gas dispersion. . The work was extended to some other configurations and geometry in order to simulate real scale situation with different kind of gases : a highly toxic dense gas such as Chlorine, a light gas stored as a liquid at a very low temperature such as Ammonia, and a gas which remains liquid at ambient temperature and pressure and is drained into an evaporating pool such as Acrolein. This work will consider the natural behaviour of the gases and the influence of longitudinal ventilation both inside and outside of the tunnel.

KEYWORDS: Tunnel, ventilation gas dispersion, toxic release, experimental study, numerical simulation

Because of the confined geometry, accidents in an underground infrastructure have a high potential of risk. The public underground infrastructure can be split into three main categories: road tunnel, rail tunnel and underground mass transport system. The risk analysis and the consequences evaluation varies as a function of the categories. The two main factors generating this differentiation are: first the intrinsic potential of risk of the infrastructure and second the relation between people and the infrastructure. This can be illustrated considering first a road tunnel in which hazardous goods transportation is allowed. In such an infrastructure, people drive around trucks that may contain hazardous goods such as flammable, explosive or toxic products, keeping in mind that people are free of their displacement in case of accident. On the opposite, in rail tunnel, people are confined in the trains but they do not circulate in the infrastructure at the same time as hazardous goods. Finally, in underground mass transport system, the intrinsic risk potential is low considering the lack of hazardous goods. This illustrates the importance of having a safety system for underground infrastructure in accordance with the risk level.

This paper is mainly focused on the road tunnel problematic. However, the discussion can be easily extended to other infrastructures.
Concerning road, an important reflexion was achieved during the past years to obtain some references scenarios in order to design the safety system for tunnels. In most of the reference guides [1] and in the QRA model [2] that is commonly used, thirteen scenarios were identified and correspond to three typologies of dangerous phenomena:

- Fire,
- Explosion,
- Toxic release.

The safety in tunnel, and mainly the ventilation system, is generally designed considering the fire risk. According to accidents reported in the past twenty years [3], fire appears to be the phenomena with the highest occurrence frequency and of course this approach seems relevant. However, the occurrence of other phenomena cannot be considered null and, even if the objective is not to design safety system on these scenarios, it is important to investigate how to manage such incident with the available safety system.
In most of the cases, ventilation in road tunnel is designed with a reference fire. This one is characterized by its heat release rate and its kinetic. The reference fire is a way to quantify the risk acceptance level. For tunnels allowed to hazardous goods transportation, this reference fire is between 100 MW as in Germany and 300 MW as recommended in Netherlands.

Considering fire as relevant scenario for the ventilation design sounds reasonable when considering first the occurrence frequency as discussed above and then the ability of the ventilation system to reduce the fire damages and casualties,. However, even if the aim is not to manage each accidental situation that can occur in tunnel, it seems important to have a global idea on the consequences of the different accidental scenarios and the possibility to manage it using an existing fire ventilation system.
Because of the pressure wave propagation velocity close to the sound velocity, explosion is not a risk easily manageable. Consequently, this situation is only dealt with when important consequences are estimated a priori, such as a building above the tunnel. In such a case, the tunnel structure is designed to resist to the overpressure generated by the explosion.

This paper offers a discussion about toxic gas management in tunnel using fire designed ventilation system. Because only few works exist on this topic, this work is a global approach. Three steps were achieved and are detailed in this paper. The first important point was the understanding of the physical phenomena relative to gas dispersion in tunnel. In this purpose, an experimental campaign was carried out. It was the inlet of the second phase that aims to determine the CFD code ability to model the dispersion of heavy gases in such a configuration. Finally, using the CFD code, several toxic releases in tunnel were modeled to apprehend consequences. Consequences were computed not only inside the tunnel but outside too considering atmospheric dispersion at the tunnel heads.

GAS BEHAVIOUR IN TUNNELS, AN EXPERIMENTAL APPROACH

Experimental apparatus

In order to improve the behaviour understanding of an heavy gas cloud in the tunnel with different ventilation configurations, an experimental campaign was performed using the INERIS fire gallery. This fire gallery is 50 m long and its section was modified to represent a tunnel section with a 1/3 scale with 3 m large and 1.8 m high. This gallery is represented on Figure 1. The duct in the upper part of the gallery enables to simulate transverse ventilation system. Longitudinal ventilation system is modeled using the main extraction fan of the fire gallery.

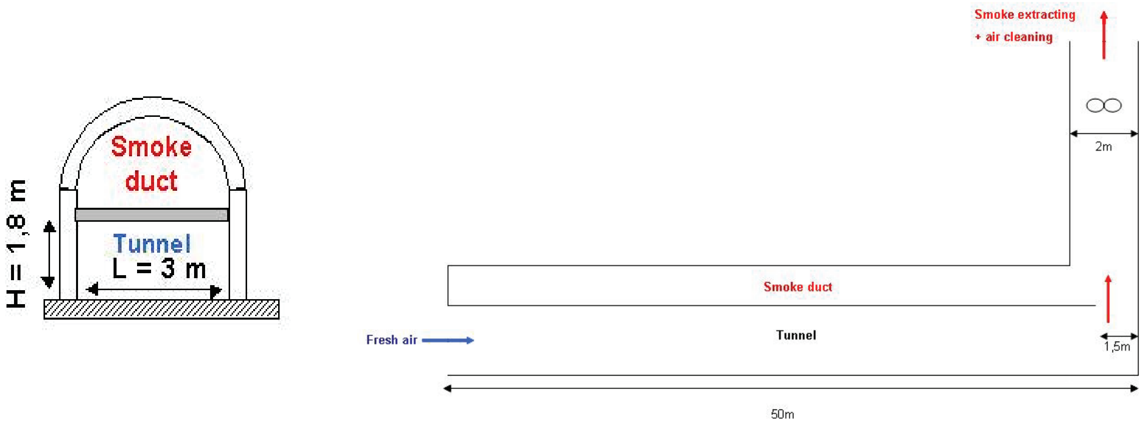

Figure 1: Fire gallery characteristics representation.

Indeed, the gallery is equipped with a fan that controls the air flow in the tunnel. Performing experiment at a given scale imposes to define the scale's impact on the dimensionless numbers. The two phenomena are the longitudinal flow dynamic represented by the Reynolds number and the buoyancy effect due to the density difference between the two gases that is represented by the Froude number. As demonstrated in previous papers about the fire part of this experimental campaign ([4] and [5]), this configuration was designed to respect the Froude number while keeping the Reynolds in a correct range.
Because using toxic gases for such experiment is impossible, a representative gas was used. At this stage. it appears important to use a gas with a molar weight higher than the one of air, in order to maintain a constant air relative density. In addition to prevent thermal effect, the gas injection should be performed at surrounding temperature. Experiments were performed using Argon, a neutral gas with a molar weight of 40 g/mol which induces a relative density of 1.4 with ambient air and using a specific injection device heating the gas after its decompression at the tank exit.
Several questions were a priori asked about gas behavior in tunnel:

- Is there any stratification of heavy gas dispersing in tunnel?
- Is there a backlayering such as the one observed in case of fire?
- Consequently, is it possible to define a critical velocity for such a flow?

Theoretical add

Before discussing about heavy gas behaviour in tunnels, some points must be highlighted mainly considering the experimental choices. Argon that was used in these experiments for safety reasons has a molecular weight of 40 g/mol that induces a density relative to air of 1.4. Considering that stratification is mainly governed by the density gradient between the gas and the air, it appears that for heavier gases the weak stratification that was observed should be stronger. As described by [7], the main scaling parameters that can be used to evaluate the stratification is the bulk Richardson number defined as:

$$Ri = g\frac{\rho_{gas} - \rho_{air}}{\rho_{air}}\frac{L}{U^2} \quad (1)$$

This means that, for a given ventilation velocity, the higher ρ_{gas} is, the more stratified the flow is. This is illustrated on Figure 2.

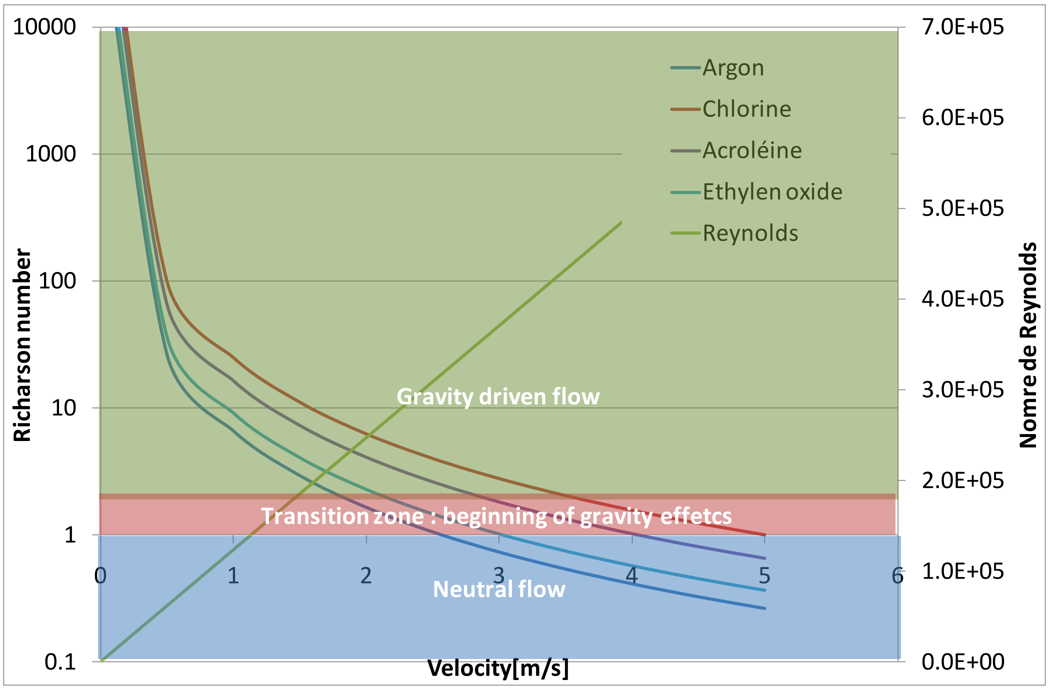

Figure 2: Theoretical curve of flow regime as a function of velocity for different gases.

This curve indicated that, for low flow velocity as those used in the experiments, flow should be stratified. This was observed in an "ideal" case: leak directed to the ground, no perturbation inside the tunnel like vehicles and no atmospheric disturbance. In such an ideal case, the experimental flow is similar to the theoretical one. This curve also shows that the stratification of heavier gas should be stronger than the stratification of argon because of their important molar weight. This induces that the influence of external parameters will be lower.

Experimental design

In order to answer questions mentioned above, the main tool is numerical visualization using several video cameras in the fire gallery. Ammonium salt (NH_4Cl) was used to seed the invisible Argon gas and then enable to visualize the flow. Because this visualization equipment cannot provide measurement values, a catharometer coupled with a scrutator was used to obtain a vertical concentration profile. Several configurations were experimentally performed to understand impact of different parameters. Experimental configurations are listed in Table 1. In this table, the modified parameter between the current case and the reference configuration is highlighted.

		Jet direction	Leak distance from tunnel entrance	Volume flow rate	Vehicles
{1}	Reference configuration	Vertical to the ground – 40 cm height	15 m	1 000 l/min	None
{2}	Counter Flow	Horizontal counter flow – 40 cm height	15 m	1 000 l/min	None
{3}	Ceiling direction	Vertical to the ceiling – 80 cm height	15 m	1 000 l/min	None
{4}	Higher rate	Vertical to the ground – 40 cm height	15 m	1 500 l/min	None
{5}	Reference configuration	Vertical to the ground – 40 cm height	10 m	1 000 l/min	Simulated 1/3rd scale cars

Table 1: Experimental configuration and their characteristics.

Considering the 1/3 length scale factor of the experimental apparatus, the leak scale factor is $(1/3)^{5/2}$, this means that the experimental leak rate of 1 000 l/min corresponds to a 15 600 l/min (or 0.43 kg/s) flow rate. This mass flow rate is representative of a chlorine or ammoniac release through a 10 mm hole for tank at ambient temperature and saturated vapor pressure. This hole size is lower than the value given by the QRA model that will be discussed later but is closed to the accidental experience.

Reference configuration

To evaluate the impact of the different parameters on the gas behavior in the tunnel, a first reference case was defined as follow. The leak is vertical and directed to the ground with a 40 cm distance between the hole and the ground, 15 m downstream the tunnel entrance. The volume flow rate of the leak is 1000 l/min and the tunnel is free of vehicles. The tunnel is longitudinally ventilated with at a velocity of 0.4 m/s. In this configuration a stratified gas layer appears downstream the leak as shown on Figure 3. It must be taken into account that only the lower part of the tunnel section were instrumented with 7 probes from the ground to 90 cm 15 m downstream the leak.

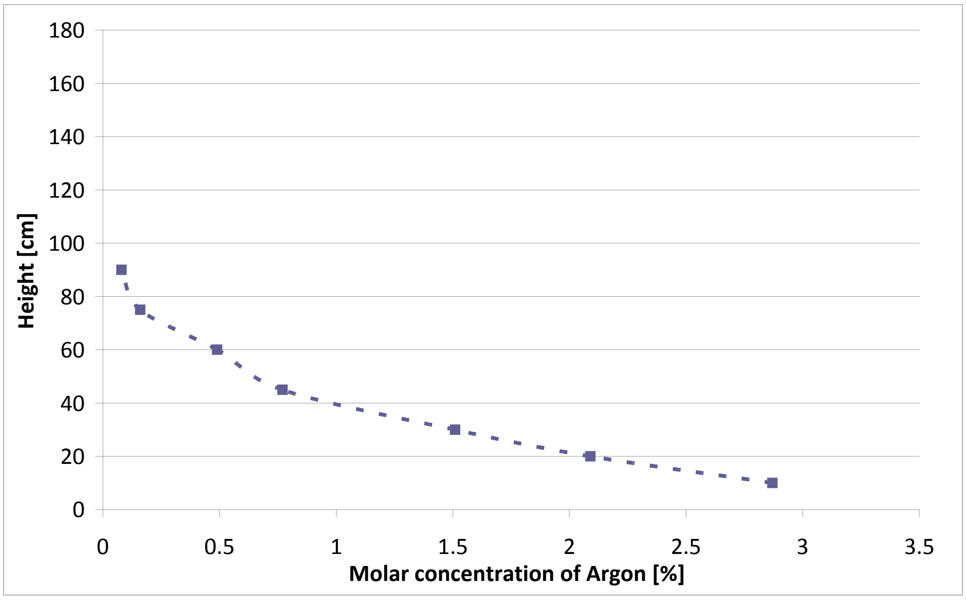

Figure 3: Vertical distribution of Argon concentration 15 m downstream the leak.

To obtain this concentration profile, measured concentrations were averaged in time. It is important to highlight that the instantaneous concentration presents fluctuations. Furthermore, external perturbations could influence the stratification.

Reference case: Numerical approach

On the basis of above described experiments and to go further in the leak impact investigation, a simulation software has been used. The well known CFD code FDS (Fire Dynamic Simulator) was used. Using a CFD code implies to be aware about its capability and limit. Therefore, comparison between its results and the experiments enables to have a good overview of the CFD code capability.
The objective of these simulations is not to validate FDS for gas dispersion modeling in tunnel but to evaluate its capability for such an application. Knowing the limit of the model, we will have a tool for extending the experimental approach to real cases.
The model was built in order to simulate the reference case using FDS. The fire gallery was modelled using a mesh with 25 cm cells in length and 10 cm in height and width.
Comparison between numerical prediction and experiment is shown on Figure 4.

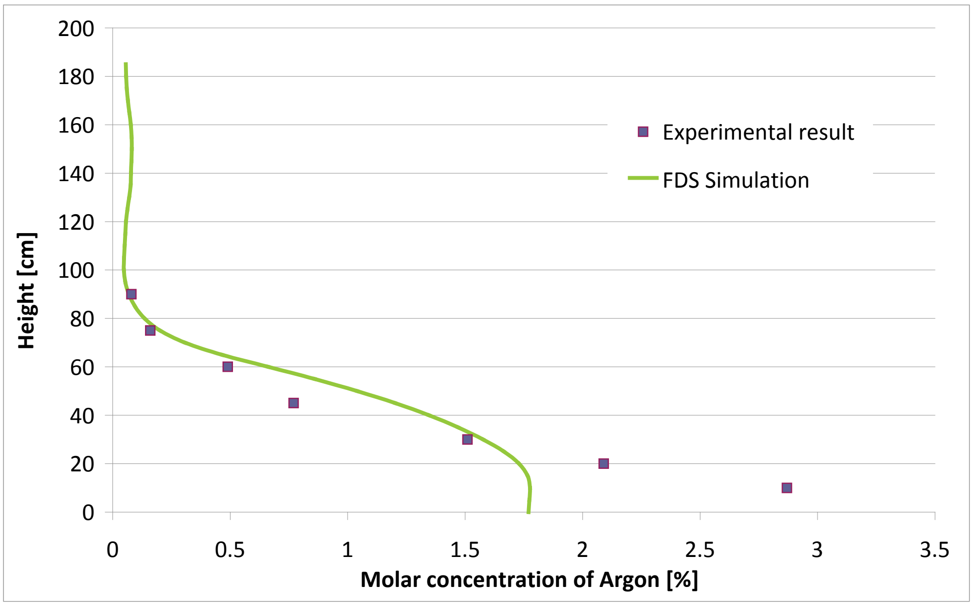

Figure 4: Comparison between the FDS prediction and measurement results.

This figure shows that, for the given reference configuration, FDS gives a quite good prediction of the gas behaviour. Of course, the two curves are not identical but the flow regime predicted is the good one: the flow presents stratification with a concentration higher in the lower part of the tunnel than in the upper one.

Impact of the leak direction

To evaluate the impact of the leak direction on the gas behavior, the jet orientation was modified from the reference case. Two directions were studied: jet directed counter flow and jet directed to the ceiling. The second case is detailed in this paper. For this configuration, the leak is simulated to be on the upper part of the truck and consequently the jet is vertical to the ceiling. The ventilation flow, position of the leak and the other parameters are identical to the one described for the reference case. The concentration profile obtained then is reproduced on Figure 5. The reference case is also plotted on this graph for comparison reasons. On this graph, concentration measurements were distributed all along the gallery height to have an overview of the whole concentration profile.

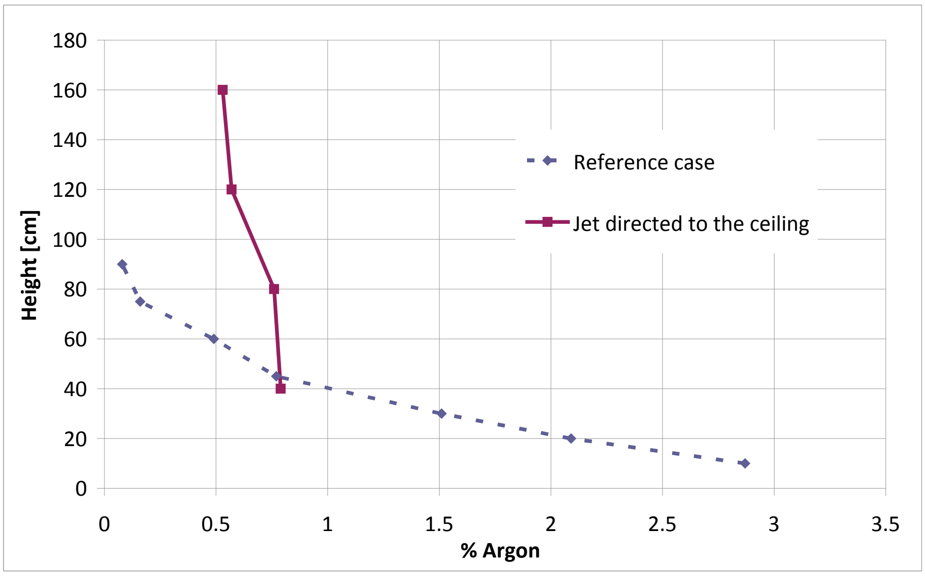

Figure 5: Vertical distribution of Argon concentration 15 m downstream the leak.

Unlike experimental configuration number 1, the stratification phenomenon does not occur for configuration number 3. This figure clearly shows that the concentration is quite homogeneous along the tunnel height. This is confirmed by video. Photography from experiment is reproduced on Figure 6.

Figure 6: Photography of gas dispersion. Jet to the ceiling case, experimental case number 3.

Consequences outside the tunnel: an illustration of the experimental configuration

As discussed above, the experimental release of 0.43 kg/s, reported to the tunnel scale, represents a 10 mm hole in a tank containing liquid ammoniac or liquid chlorine stored under vapor pressure at 20°C. Before going any further, it appears relevant to wonder about the consequences of such a leak outside the tunnel, for an estimated real configuration. Considering a 48 m² cross-section tunnel with a ventilation velocity of 0.7 m/s, corresponding to the experimental velocity converted to real scale, the dispersion was modeled using the integral model provided by PHAST. Doing this implies to assume a homogeneous concentration at tunnel head. The mass air flow is then around 40 kg/s, which induces a toxic gas mass concentration of 1%. Computations were achieved for those two cases and results are plotted on Figure 7. Reader must be particularly attentive to curve scale that differs because the difference between the two gases threshold.

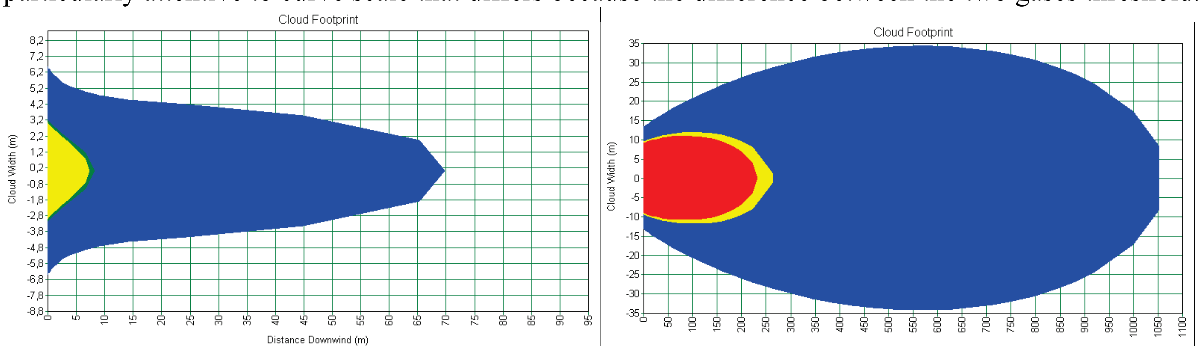

Figure 7: Experimental configuration - toxic gas dispersion outside the tunnel assuming ammoniac leak (left) and chlorine leak (right). Non reversible (blue), lethal (green) and significant lethal (yellow) for 10 minutes exposure threshold are plotted.

Considering the significant effects outside the tunnel of the free dispersion of chlorine inside the tunnel, it is relevant to wonder about the impacts of longitudinal ventilation outside the tunnel. Inside the tunnel, a higher ventilation velocity enables to maintain the upstream part of the tunnel free of toxic gases and introduces dilution which should to diminish the external effects. The atmospheric dispersion was then carried out with a 3 m/s ventilation induced air flow velocity. Dispersion at the tunnel head is plotted on Figure 8.

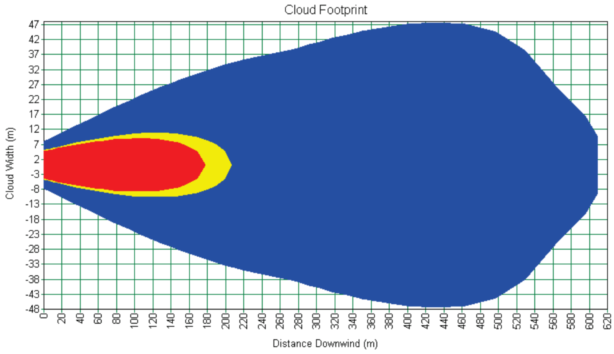

Figure 8: 3 m/s ventilation velocity chlorine dispersion outside the tunnel assuming ammoniac. Non reversible (blue), lethal (yellow) and significant lethal (red) for 10 minutes exposure threshold are plotted.

This comparison clearly shows the ventilation flow rate impact on the outside gas dispersion: the cloud expends a little further widthwise but the footprint is shorter downstream (600m instead of 1050), which is beneficial.

Experimental campaign conclusion

As mentioned in the introduction of this section, experimental campaign aims to answer three questions:

- Is there any stratification of heavy gas dispersing in tunnel?
- Is there a backlayering such as the one observed in case of a fire?
- Consequently, is it possible to define a critical velocity for such a flow?

Concerning the first item, the answer is more complex than in fire cases. When dealing with fire cases, hot smokes are emitted along a vertical direction from ground to ceiling. Because of the temperature difference, smokes are lighter than the ambient air producing a stratification layer. In such case, it is possible to define well known stratification criteria [6]. Considering dense gas, such a criterion should be based the equation not on temperature but using directly the concentration difference. However the pertinence of this parameter appears limited. Indeed, in case of fire, the main is the fire heat release rate. The flow in the combustion zone is driven by the free convection phenomena due to the high density of heat released. In case of toxic leak, the flow due to the leak is a jet for which the direction cannot be predicted. This induces that it appears difficult to have a precise description of toxic cloud dispersion in tunnel. It also appears that without considering stratification, using CFD may help to adjust ventilation velocity to minimize the effects of toxic gases both inside and outside the tunnel.

Figure 9: Observation of a gas layer in the lower part of the tunnel.

These conclusions are not opposite to the possibility to define a critical ventilation regime. Such a regime can be used to maintain the upstream part of the tunnel safe. Experiments show that a gas layer in the lower part of the tunnel can be observed for some configurations. This phenomenon of a gas layer that goes counter flow can be called low-backlayering by similarity with the fire backlayering phenomenon.

In experiments, it appears that this phenomenon is not as stable as smokes stratification in a fire case. The gas dispersion was highly depending on gallery surrounding conditions, such as external wind. However, it appears clear that, all other parameters fixed, raising the ventilation rate induce a low-backlayering length reduction.

This section also shows that the CFD code FDS was able to predict the flow regime in one case of heavy gas dispersion in tunnel. This results shows that numerical results is good enough to use the code in order to go further and using it to simulate real scale configurations.
Finally, the comparison of the conditions outside the tunnel in cases with and without ventilation was performed, using models based on the experimental results. This shows that ventilation system design for fire fighting can be used not only in order to push the cloud downstream the leak in order to prevent the toxic gas to invade the whole tunnel but also in order to dilute toxic gas prior to its dispersion in the atmosphere.

To summarize, experimental campaign shows that stratification may exist for heavy gas leak in tunnel. However this stratification depends on leak configuration and external parameters such as atmospheric conditions. Second, experiment shows the possibility to obtain a low-backlayering layer and also the possibility to define a critical regime for such dispersion.

CONSEQUENCES OF GAS LEACKAGE IN TUNNEL

The toxic release scenario in tunnel is rarely considered. If such a leak is not frequent, such an accident would have catastrophic consequences. In the QRA model, several configurations were proposed:

- 50 mm in diameter hole in a chlorine tank that induces a 45 kg/s liquid leak,
- 50 mm in diameter hole in a ammoniac tank that induces a 36 kg/s liquid leak,
- 100 mm in diameter hole in an acrolein tank that induces a 24.8 kg/s liquid leak,
- 4 mm in diameter hole in an acrolein tank that induces a 0.02 kg/s liquid leak.

It appears that those values are prudent for evaluating a hazardous line transport as a global view but are over estimated for consequences prediction in tunnels. Accidental experience shows that the hole diameter in case of leakage on a hazardous truck is lower than 25 mm. For this reason, a 4kg/s chlorine release was chosen to represent the highly toxic gaseous case and a 100 m² pool evaporation was used for toxic liquid. Of course, other toxic products can be released and those scenarios just aim to be representative. According to these elements, we wonder about the impact of a toxic release in tunnel considering existing system. Gas dispersion was modeled in a 400 m long tunnel with a 78 m² section equipped with a ventilation system that is able to ensure a longitudinal velocity of 3 m/s. Simulation were achieved using the CFD code FDS.

Chlorine leakage: Consequences of a highly toxic gas

Chlorine was chosen in order to model the consequences of a gas release in tunnel because it is a highly toxic heavy gas. Its molar weight is 70 g/mol which induces a density of 2.4 relative to air. Because of the high toxicity of this gas, consequences have to be studied not only in the tunnel but outside too. The toxic effect thresholds for chlorine are reminded in Table 2.

	1 minute exposure	10 minutes exposure	20 minutes exposure
Non reversible toxic effect	110 / 0.03%	41 / 0.01%	30 / 0,007%
Lethal toxic effect	910 / 0.22%	280 / 0.07%	200 / 0.05%
Significant lethal effect	1082 / 0.26%	324 / 0.08%	226 / 0.05%

Table 2 : Chlorine toxic effect threshold concentration in ppm and in mass fraction (ppm / mass fraction).

Simulations were achieved to provide a first description of the gas concentration inside and outside the tunnel with and without ventilation. In the ventilated case, a 3 m/s ventilation velocity was used. The mass release rate of chlorine for these simulations is 4 kg/s. The simulation results of these two configurations are plotted on Figure 10 and Figure 11. The maximum concentration on these pictures is set to 0.07% that corresponds to the lethal effect for 10 minutes exposure.

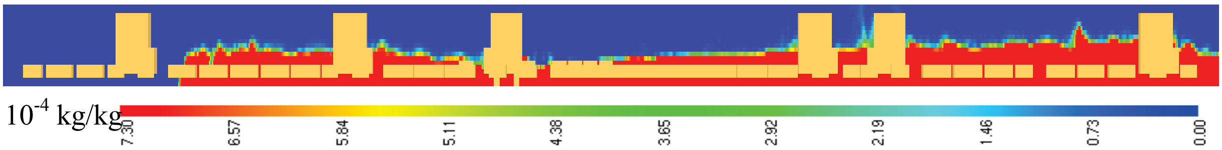

Figure 10 : Mass concentration distribution in a side view centered on the leak five minutes after the leak beginning in an unventilated tunnel.

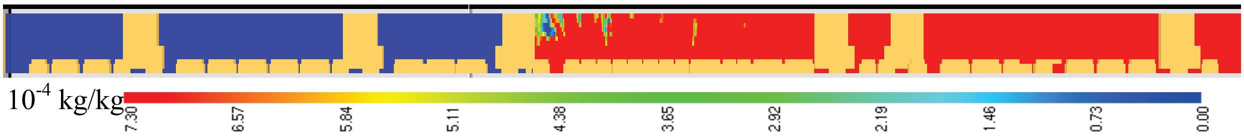

Figure 11 : Mass concentration distribution in a side view centered on the leak 75 s after the leak beginning with 3 m/s ventilation velocity.

These two results show that, for a leak 10 times smaller than the one defined in the QRA model, the consequences inside the tunnel would be catastrophic.
These results also shows that the concentration at the tunnel head is higher than threshold and of course, consequences will propagate outside the tunnel. This can in urban configuration cause dramatic consequences. To estimate these consequences, the toxic gas dispersion was modeled considering the tunnel head as a release with a concentration equal to the average concentration at the outlet.
Using these averaged concentration and the computed velocity at the tunnel end, an integral dispersion model was used to predict the atmospheric dispersion of the toxic cloud. The dispersion results are given underneath on *Figure 12* for the ventilated tunnel case. Consequences of the unventilated case cannot be modeled using an integral model since the velocity at the head is out of the scope of such a model.

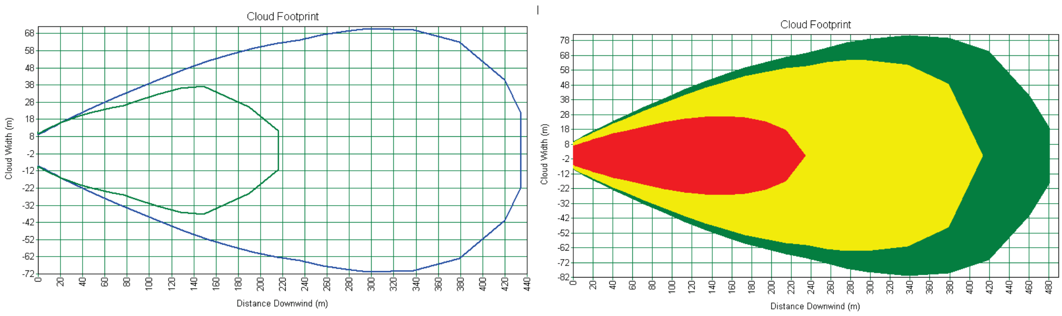

Figure 12: Toxic cloud footprint of lethal effect for 10 minutes exposure for atmospheric class F3 (blue line) and D5 (green line) on the left and foot print for F3 class with significant lethal effect for 1 (red), 10 (yellow) and 20 (green) minutes of exposure on the right.

These results show that, in case of an highly toxic gas release in tunnel, consequences would be catastrophic both inside and outside the tunnel, generating consequences up to several kilometers away from the tunnel's head.

Liquid leakage: Pool evaporation consequences

Considering hazardous goods transportation on road, it is important to also consider toxic products which remain liquid at ambient temperature and pressure and create a pool which evaporates. Acrolein is considered in this paper to provide an overview of such product leak consequences. The toxic thresholds of this product, given in Table 3 are very low.

	1 minute exposure	10 minutes exposure	20 minutes exposure
Non reversible toxic effect	62	8	4
Lethal toxic effect	557	73	40
Significant lethal effect	650	85	46

Table 3 : Acrolein toxic effect threshold concentration in ppm.

To model the toxic effect of such an event, a 100 m² pool was assumed and evaporation was computed based on ventilation velocity and pool surface, taking into account the physical characteristics of the products. These simulations shows that, toxic thresholds being particularly low for such a product, lethal concentrations are easily reached inside the tunnel, as shown on Figure 13.

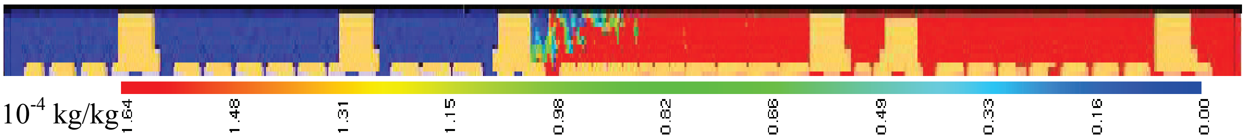

Figure 13: Acrolein dispersion in real scale tunnel considering a 3 m/s ventilation velocity. The mximum value that is represented is the toxic threshold for 10 minute exposure (73 ppm (mol fraction) = 1.4e-4 kg/kg (mass fraction)).

This figure indicates that the toxic gas does not stay stratified downstream the leak but shows that a 3 m/s ventilation velocity enables to maintain the upstream part in fresh air. This case has to be compared with the situation without velocity represented underneath on Figure 14.

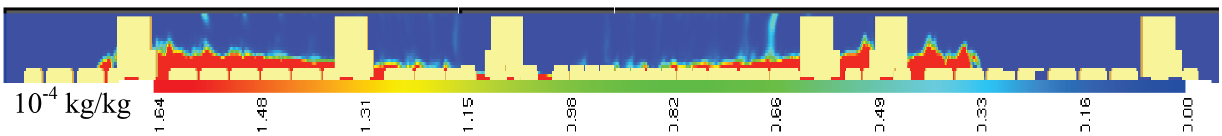

Figure 14: Acrolein dispersion in real scale tunnel without ventilation. The maximum value that is represented is the toxic threshold for 10 minute exposure (73 ppm (mol fraction) = 1.4e-4 kg/kg (mass fraction)).

In this configuration, the conditions seem better but acrolein will sooner or later mix with fresh air, get warmer and lighter and reach men height. So in both cases, the consequences in tunnel are dramatic but at least using fire design ventilation system enables to keep part of the tunnel free of toxic gases. This solution however induces consequences outside the tunnel because of the release of a large quantity of toxic product. The outside effects for a ventilated tunnel were computed using an integral dispersion model with PHAST. Dispersion results are plotted on the figure 15 underneath.

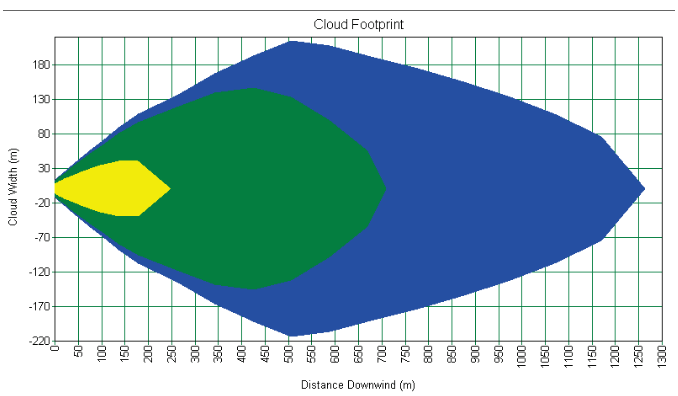

Figure 15: Acrolein dispersion outside the tunnel, foot print for F3 class with significant lethal effect for 1 (red), 10 (yellow) and 20 (green) minutes of exposure duration.

These computations show again the difficulty to manage a toxic gas release in confined geometry such as tunnel. Even if the fire design ventilation system enables to keep the upstream part of the tunnel free of gas and then make the evacuation safe for driver blocked in that part, this solution which is good for uncongested tunnel, has consequences outside the tunnel that can be worse than for the unventilated case.

CONCLUSIONS

The paper is dedicated to the toxic gas dispersion problem in semi confined infrastructure like road tunnels. In these tunnels, the ventilation safety system is commonly based on the design fire curve in order to be able to manage smoke. This approach seems relevant considering the occurrence frequency for a fire in tunnels as shown in the accidental experiment knowledge. However, in tunnels where hazardous goods transportation is allowed, some other accidental scenarios are possible such as explosion or toxic gas dispersion. If using the ventilation system for explosion case is not relevant, for the gas dispersion cases the ventilation system can be a mean to prevent dramatic consequences. However, we should keep in mind that designing the ventilation system for managing dense gas is not realistic, considering the low probality of this kind of accident to occur. The objective of this paper was then to propose a reflexion on the fire design ventilation system impact on the gas dispersion in tunnels.

First of all, an experimental campaign is described. This campaign was achieved using Argon in a 1/3rd scale model. This campaign enabled us to understand the gas behaviour in the tunnel and mainly the influence of several external parameters that directly impact the stratification of the cloud. This campaign also enables to evaluate the FDS code capability to predict gas dispersion inside the tunnel. The results have shown that using this code for enlarging the scope of the experimental campaign is coherent. Finally, on the basis of this experimental campaign, it was possible to have a first discussion on the fire design ventilation system impact on the toxic gas dispersion both inside and outside the tunnel.

In the last part of this paper, some real scale configurations were modelled. This aims to enlarge the scope of the experimental campaign as described above. Two cases were discussed: a toxic gas release and an evaporating toxic liquid. For both cases, calculations show that consequences inside the tunnel could quickly become dramatic. They also show that ventilation system can be used to prevent from having toxic gases upstream the leak and then, in uncongested tunnels, to enable drivers protection in that part of the tunnel. However, for those two cases, atmospheric dispersion has to be considered in order to have a global view of the toxic impact. Using the ventilation system induces a toxic source term from one tunnel entrance and the ventilation procedure should be designed in order to minimize the toxic impact not only inside the tunnel but also outside.

This paper is a first reflexion of the available possibilities to manage ventilation system in case of toxic release in tunnel. Both the experimental campaign and real cases modelling show that consequences must be considered not only inside but also outside the tunnel.

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