Characterization of hazardous phenomena

The accidents recorded in the ARIA database present 3 major types of hazardous phenomena, namely: fires, discharges of hazardous substances, and explosions. The breakdown of these accidents in the ARIA base by type of event is listed in the following table, as a percentage of the number of French accidents involving classified facilities, i.e. out of a total of 22,585 cases between 1992 and 2012, inclusive, with 900 cases in 2012 alone.

Type of event (not mutually exclusive)	1992-2012 (%)	2012 (%)
Fires	64	61
Discharges of hazardous substances	43	50
Explosions	7.4	6.5

Fires and discharges of hazardous substances constitute the most frequent type of accident event. Though fewer in number, explosions still represent a high potential for destruction.

This document seeks to demonstrate how a better understanding of hazardous phenomena can, in particular, improve modelling of such phenomena; moreover, for two actual cases of fire and explosion, the correlations derived between existing numerical models and specific events will be presented. Some selected recommendations will also be provided, with the aim of enhancing the state of knowledge on hazardous phenomena through use of feedback.

1. Benefits derived from an improved knowledge of hazardous phenomena

The prevention of accidental risks implies a series of coordinated actions focusing on:
- reducing risks at their source by means of managing inventory;
- controlling urban development around industrial sites presenting a hazard potential (by including the French approach contained in Technological Risk Prevention Plans developed for upper-tier Seveso sites);
- adapting and regularly testing emergency rescue plans;
- disseminating prevention-related information to the public.

Regulating urban development at the periphery of industrial sites requires in-depth knowledge of potential accident scenarios, in particular their effects on the environment.

To assess the vulnerability of a given point and measuring the sensitivity of "targets" located across the zone in the presence of a given type of impact (e.g. pressure surge hazard), three tools are available:
- post-accident feedback in cases where an accident has already occurred;
- numerical modelling of the effects of hazardous phenomena;
- experimentation.

The first two approaches are related in the sense that the study of accidents helps improve calculation tools, and these are used to determine effects zones to limit the consequences of accidents. The experiment can be used to confirm the teachings of an accident or to understand the mechanisms and to improve the models.

Continuous improvements in modelling pave the way to establishing more accurate safety reports for industrial sites and to more effectively designing response devices or equipment as part of a strategy addressing the array of challenges, be they economic, environmental or human.

2. Modelling approach

The basic principles involved in modelling a fire, hazardous substance discharge or explosion rely on the same approach, whose first step consists of characterising a source term (e.g. volume of combustible present, physical characteristics). The next step entails modelling the propagation of this source in the environment based on meteorological conditions (wind speed, ambient temperature, etc.) or the environment (terrain, obstacle, building ...). This approach is aimed at modelling the "effect" of this phenomenon so as to compare it with known thresholds of the physical effects on "targets".

For purposes of review, the primary thresholds for "regulatory" physical effects (i.e. thresholds applied in safety reports) in the event of fire are as follows:

- with respect to human health:
  - 3 kW/m^2: threshold for irreversible effects;
  - 5 kW/m^2: threshold for the first lethal effects;
  - 8 kW/m^2: threshold for significant lethal effects.
- with respect to built structures:
  - 5 kW/m^2: threshold of significant destruction of windows;
  - 8 kW/m^2: threshold for domino effects and serious structural damage;
  - 16 kW/m^2: threshold for very serious structural damage (excluding concrete).

In the event of explosion, these regulatory thresholds are:

- with respect to human health:
  - 20 mbar: threshold for indirect effects;
  - 50 mbar: threshold for irreversible effects;
  - 140 mbar: threshold for the first lethal effects;
  - 200 mbar: threshold for significant lethal effects.
- with respect to built structures:
  - 20 mbar: threshold for widespread shattering of windows;
  - 50 mbar: threshold for slight damage;
  - 140 mbar: threshold for serious damage.

3. Modelling of a fire

Event description

The analysis of ARIA accident 22459, which occurred on 18th May 2002 in Dunkirk,[1] exposes some pertinent factual elements:

ARIA 22459 - 18 May 2002 - 59 - DUNKIRK
19.20 - Oil refining
In a plant manufacturing bitumen, base oils and other by-products, an explosion occurred on a 140-tonne tank storing an additive used in the road bitumen composition that contained **2 polymers with high flashpoints**. Insulated and **nearly full at the time of the accident**, this tank was equipped with an agitator and heating coil (**for a viscous product held at over 150°C**), along with a temperature indicator, a nitrogen inerting device and a vent. Due to the blast effect, the tank roof was blown off and landed nearby, while **the tank ignited**.
The internal emergency plan was activated. **The plant operator brought the fire under control within 10 min** using two turret nozzles. External fire-fighters were notified, though their presence was not required onsite.
No injuries were reported and **property damage was limited to the tank itself**. The wind was not blowing in the direction of neighbouring residences, but instead towards the docks.
Nearly all substances remaining in the tank were transferred to another container. The quantity of product lost during the fire was estimated at 1 m^3. The retention basin was later drained.
At the Inspectorate's suggestion, the Prefect signed an emergency order suspending supply of this process additive for the time required to conduct the necessary investigations and appraisals, which revealed that **the 2 polymers present in the mix were indeed capable of decomposing in the presence of heat. The first one had decomposed into a substance with a flashpoint below 50°C and a highly flammable monomer with a flashpoint below 0°C**. The second polymer in the mix had the potential to release **extremely flammable gases**. This accident was caused by the slow decomposition of both additive constituents, which in the presence of air yielded organic peroxides or other substances capable of spontaneous combustion. These ingredients, which had been stored for a long time without any agitation, were also responsible for a large accumulation of static electricity. The simple nitrogen flushing of the tank had produced an air intake.
Beyond the immediate measures adopted, the Inspectorate proposed that the Prefect introduce the following equipment: continuous measurement and automatic regulation of temperature connected to a high-level alarm; nitrogen inerting triggered by pressure control; intensity controls on the agitator motor; and a flap valve vent or equivalent to limit air intake. A study was also requested on the feasibility of extending these devices to the site's other flammable liquid tanks.

[1] This accident was already the topic of a presentation at the IMPEL seminar on feedback from industrial accidents (Dijon, Nov. 4-5, 2003).

The detailed accident report (downloadable from the site www.aria.developpement-durable.gouv.fr) indicated that the tank had a capacity of 185 m³ (diameter: 6 m, height: 6.5 m). The composition of the suspected additive was also confirmed, i.e.: a mix of two polymers, one of which decomposed into a highly flammable substance in the presence of heat. During the fire, a flame height on the order of 10 m could be observed from the ground.

The following photographs reveal the physical state of the installations after the accident.

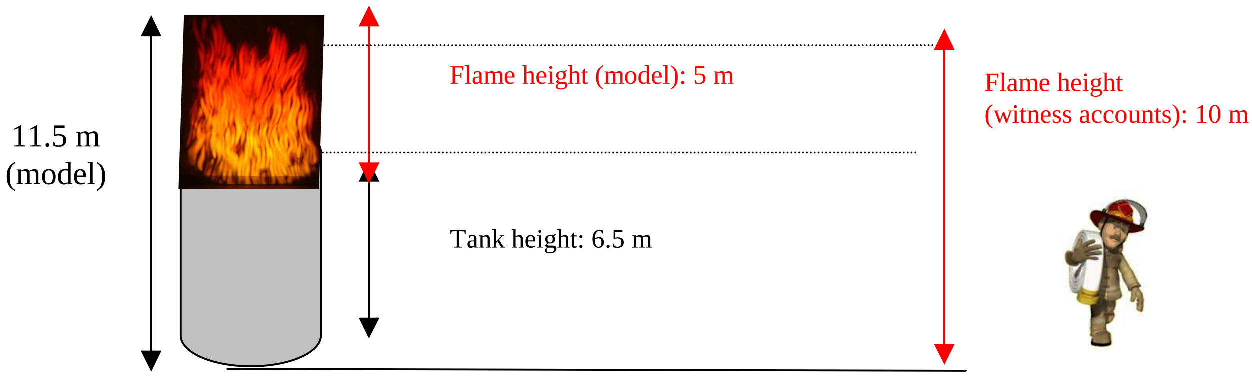
Storage zone - All rights reserved

Tank roof - All rights reserved

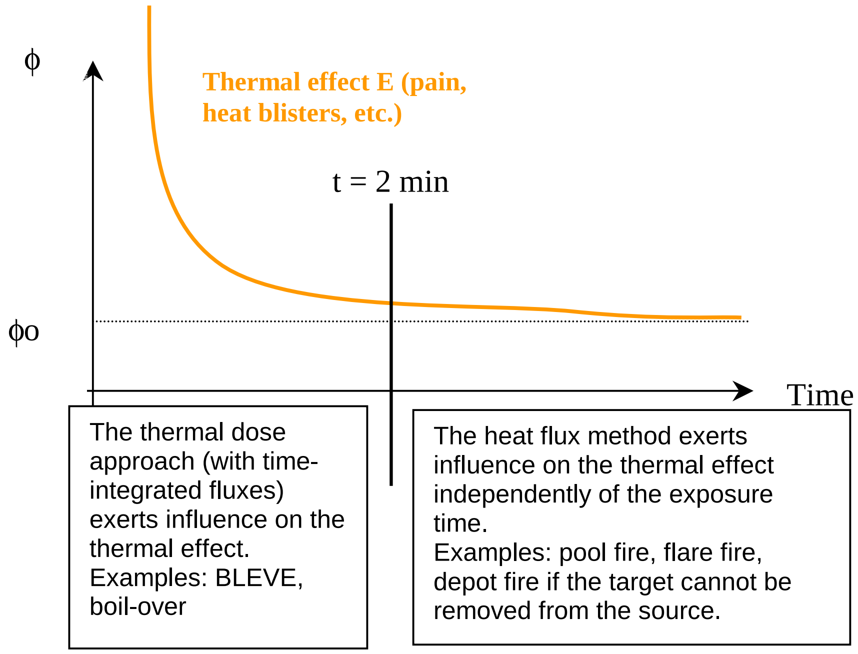
Numerical results

In applying the so-called "solid flame calculation model" appended to the 31st January 2007 circular integrated in the circular of the 1st May 2010 relative to hazard studies on deposits of flammable liquids, we have derived the following results by adopting the hypothesis that the characteristics of this originating product were comparable to those of a hydrocarbon (i.e. heat of combustion around 40 MJ/kg and a combustion speed on the order of 0.04 kg/m²/s).

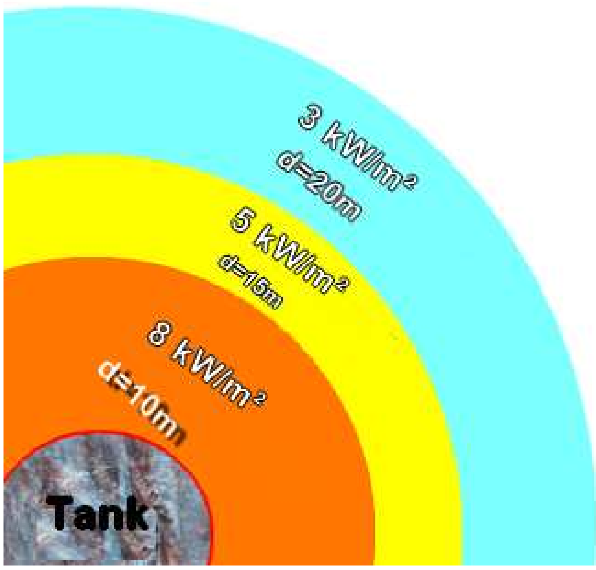
The flame height was estimated at approx. 5 m above the top of the tank, which compares well with witness accounts indicating a 10-m flame height.



In assuming that the fire duration (10 minutes) exceeded the 2-minute threshold that defines the boundary between the thermal dose approach and the heat flux method (see diagram below), the following results are obtained for the generated heat fluxes.



Source: INERIS



Results of thermal effect modelling

Very little information is available in the accident summary on thermal effects, besides the fact that the damage is limited to the tank. Calculations suggest a threshold domino effects and serious damage on structures (radiative flux of 8 kW/m²) at about 10 m from the tank. Based on photographs of the accident scene, some equipment was located within 10 m of the tank.

The calculation performed was thus on the conservative side, which could be explained by:
- materials and structures involved in the accident;
- the hypothesis adopted, according to which the product behaved like a hydrocarbon.

4. Modelling of an explosion

Event description

ARIA 33085 - 7 May 2007 - 01 - DAGNEUX

49.41 - Road freight transport

At 8:24 pm, a passer-by noticed a cab fire in one of the three lorry tankers in a convoy transporting **liquefied petroleum gas (LPG)** that were parked at the premises of a landscaping firm. The fire quickly spread and around 9:15 pm, an initial blast occurred followed by one or several others; 2 of the 3 cisterns exploded (BLEVE-type incident), and the 3rd was thrown onto the roof of a neighbouring plant. The subsequent explosions and fires caused extensive **property damage within a 900-m radius, including the destruction of 4 warehouses covering 1,000 m² floor space each.**

Gendarmes set up a safety perimeter encompassing the entire industrial park; a motorway and the Lyon-Ambérieux railway line were closed for several hours. A large smoke cloud rose vertically, but no order was issued requiring evacuation of the local population.

Five adjacent businesses were destroyed or heavily damaged and in all some 20 industrial installations within the park sustained varying degrees of damage, resulting in 60 employee redundancies. A 100-kg metal part was projected through the roof of a single-family dwelling 700 m away.

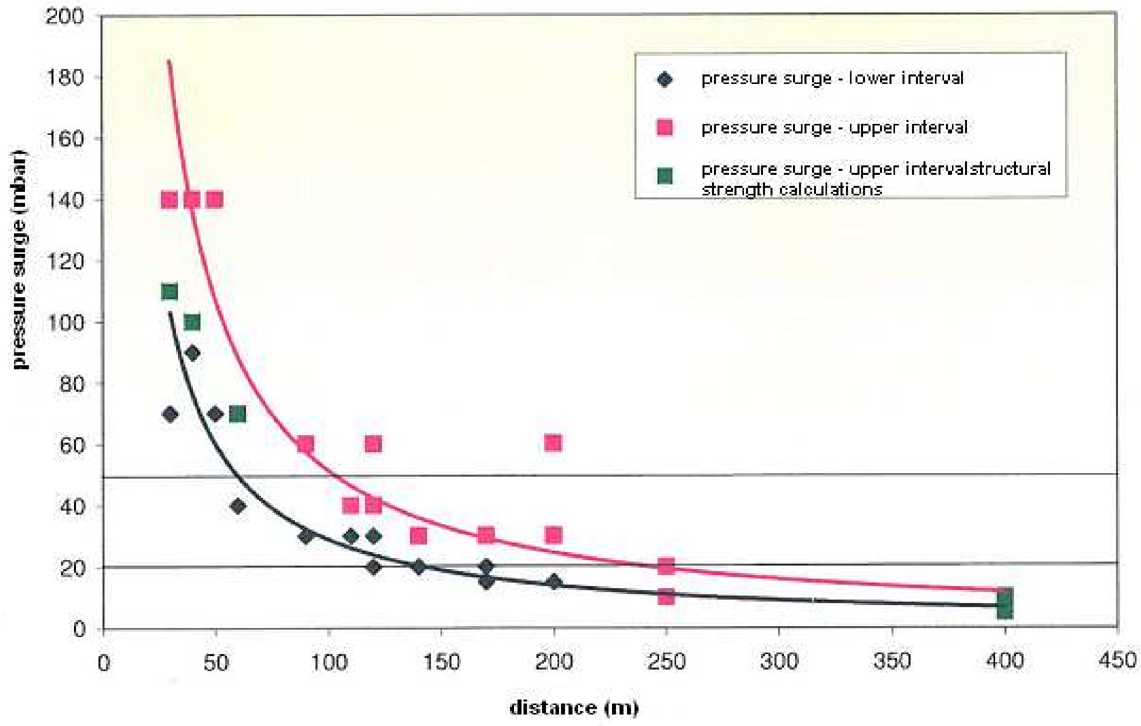
Three fire-fighters and two gendarme officers were slightly injured; **some 20 fire-fighters stationed 200 m from the explosion experienced ear, nose and throat disorders to at least some extent.**

A judicial investigation was carried out to determine the origin of this accident, without overlooking the possibility of criminal act. **Of the 3 cisterns involved, one had contained 2.5 tonnes of propane and another several hundred kg. The third cistern was empty but not yet degassed.** An independent appraiser was commissioned to collect technical data on the accident**. Initial results indicated that effects from the blast extended 50 m due to thermal radiation and up to 400 m (shattered window panes) due to the pressure surge.** Pieces of cistern, sprayed as far as 900 m, destroyed a company premises located 100 m from the lorries and burned a hedge at a distance of 250 m.

Damaged building - All rights reserved

Subsequent to this accident, the INERIS Institute estimated the effects of pressure and the distance over which the pressure surge had caused damage (see detailed accident data sheet downloadable from the site: www.aria.developpement-durable.gouv.fr). Pressure effects could be observed as far as 400 m away (a few shattered windows).

During their survey, appraisers also noted that the effects of pressure were more widespread than thermal effects (within a 50-m radius), which in general appeared as broken windows, cracks in building walls and the destruction of cladding.



Estimation of the effects of overpressure by INERIS from damage during the Dagneux accident.

The vehicles involved in this accident carried limited loads of 9 tonnes; their cisterns were either empty or nearly empty.

Numerical results

A numerical evaluation of the distances of pressure surge effects for an empty LPG cistern, as listed in the 10th May 2010 Ministerial circular relative to the methodological rules applicable to safety reports, is provided in the following table:

PROPANE or BUTANE, empty liquid tank						
Mobile tanks	Burst pressure	300 mbar	200 mbar	140 mbar	50 mbar	20 mbar
Tanker car 119 m3	27 bar	50	60	80	185	370
Tanker car 90 m3	27 bar	45	55	70	170	340
Road tanker 20 t	25 bar	35	45	65	130	260
Road tanker 9 t	25 bar	25	35	45	100	200
Road tanker 6 t	25 bar	25	30	40	90	180

Distances for pressure surge effects (in m) - listed in the circular issued on 10th May, 2010

These results appear to be consistent overall with the distances estimated after the accident.

5. Recommendations for handling feedback

As can be seen in the two examples highlighted in this document, the investigations conducted for feedback purposes subsequent to industrial accidents provide significant opportunities for improving our state of knowledge on hazardous phenomena. In this pursuit, it is essential that the investigation:

- generate technical information on the substances involved (physicochemical characteristics, toxicity, safety data sheets, etc.);
- yield the precise nature of storage facilities and their associated basins (dimensions, state of repair, component materials, etc.);
- evaluate the distances over which effects are recorded (shattered windows, thermal effects on structures and vegetation, length of polluted banks, distance from the point where the leak entered the watercourse);
- determine the flow rate of leaks, size of pipe breaks in the case of a pipe leak, number of individuals present in the vicinity of the site (in particular third parties);
- identify the number of injured, types of lesions caused and their position as the accident unfolded;
- collect background information on the meteorological conditions (wind speed, ambient temperature, etc.) and potential physical barriers capable of modifying the spatial evolution of hazardous effects (wall, bund wall, infrastructure, etc.).

The analysis of the site provided immediately following the accident must also be examined in fine detail.

Conclusion

The numerical modelling of phenomena has become a critical step in all sectors of society, including risk evaluation (whether industrial; natural or environmental).

Such modelling is commonly used to answer the question "*what would happen if…?*", due to the inability of physically replicating the experiment. It also allows testing a hypothesis that has not been taken into account when building the infrastructure, e.g. to measure the strength of a building or facility when exposed to a more intense natural hazard than that used as a design reference.

Though based on relatively simple models, the numerical results provided herein have proven to be quite close to the values recorded during actual accidents.

Against the backdrop of continued advances in the capacity of scientific calculations, interpretation of these numerical methods, in conjunction with post-accident feedback, has contributed to improving our knowledge of hazardous phenomena.