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Analysis of the explosion of a liquefied-natural-gas road-tanker

Segurity

This article describes a liquefied-natural-gas tanker accident in the Spanish province of Murcia, with subsequent ignition and explosion of the cargo. The effects were notable in terms of thermal radiation, overpressure blast wave and flying shrapnel. This was the second known accident of this type in the world. In 2002 a similar accident occurred in Tivissa (Tarragona). This article looks at the possible causes, draws conclusions and puts forward recommendations for avoiding accidents of this type in the future.

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On 20 October 2011 a road tanker suffered an accident in Zarzalico in the municipal district of Lorca in the Spanish province of Murcia. After the crash the tanker almost immediately caught fire and the load subsequently exploded; the lorry driver died in the aftermath of the accident. At the moment of the accident the tanker, carrying 46,000 litres (21,589 kg) of liquefied natural gas (LNG), was heading for the town of Fonelas (Granada) after loading up with its cargo at a Cartagena plant. According to the categorisation of accidents laid down in Spain's Basic Civil Protection Directive (*Directriz Básica de Protección Civil*) this was classed as a type 4 accident at the start, building up to type 5 by the end.

On 22 June 2002 another road tanker of similar characteristics suffered an accident in Tivissa (Tarragona), which also resulted in a fire and explosion. Until that time none of the LNG tanker accidents recorded around the world had ever resulted in an explosion of the cargo. The Zarzalico accident bore some resemblance to the Tivissa accident but there were also certain appreciable differences in the former case: a road with heavy traffic, a nearby petrol station, a significant number of people and, above all, the arrival of the firefighters at the accident site before the explosion while the tanker was still on fire. Forty seven minutes after their arrival the tanker exploded (the total time from crash to explosion was 7 minutes). In the Tivissa crash the firefighters were not yet on the site when the tanker exploded. In the Zarzalico accident, therefore, there are many eye-witness accounts from those nearby at the time and the rescue workers themselves.

Description of the scenario and accident

The accident happened at kilometre point 3.5 of the A-91 motorway running from Puerto Lumbreras to Granada. The height above sea level of the accident site is 856 metres. About 150 metres from the accident spot, on the other side of the road (the southwards carriageway), stands a petrol station with cafeteria-restaurant, shop and HGV drivers' resting point. Ninety metres away, next to a service road running parallel to the accident road (northwards), stands an inhabited country lodge. Alongside the explosion site, on the hard shoulder of the motorway runs an earth and rock embankment about 10 metres high on average.

Figure 1. Bird's eye view of the accident area. Source(1)

About 8:00 hours that morning a lorry carrying large prefabricated concrete sheets stopped on the motorway hard shoulde due to a breakdown. About twenty minutes later the road tanker ran into the back of the parked lorry. As a result of the crash the driver lost control of the road tanker, which ran on past the flat-bed lorry, broke through the hard-shoulder crash barrier and became wedged in a ditch against the embankment. The lorry ended up on its wheels, leaning over to the righ due to the slope of the ditch; the cab was jack-knifed back towards the trailer, remaining trapped between trailer and embankment.

Figura 2. Situation of the vehicles after the accident. Source[2].

After coming to a stop the road tanker burst into flames. Several eye witnesses who were in the petrol station and the cafeteria at the time bear this out. The declarations of the flat-bed lorry driver also confirm this circumstance, since he tried to help the road tanker driver but could not get close due to the fierceness of the flames.

Emergency response

An on-the-spot witness called the 112 emergency service, thereby activating the accident-response mechanisms. The time by now was 8:21 and the first fire-fighting crew was mobilised from Lorca fire station, belonging to the *Consorcio de Bomberos de la Región de Murcia* (Consortium of Firefighters of the Region of Murcia), at about 31 km from the crash site. The initial information they received upon leaving the depot was that of a lorry fire with the driver trapped inside. On the journey they were told that the crash might involve a natural gas tanker. The first action on arrival was to cross-check the information received during the journey. Involvement of a liquefied natural gas tanker was soon confirmed, and also that the driver was trapped inside the cab, which by then was enveloped in flames. They also observed the almost complete loss of the road tanker shell and part of the insulation. Smoke emission had diminished considerably, suggesting that the fire was now feeding solely on the tanker contents.

Figure 3. View of the road tanker upon arrival of the fire-fighting force. Source: On-the-spot witness.

Acting on information received, and given the risk of a potential explosion, the emergency team decided to cordon off the area to a radius of six hundred metres, ordering the Guardia Civil to cut off motorway traffic in both directions at this distance. The fire-fighting vehicles retired to an initial distance of about one hundred and fifty metres and arrangements were also made to evacuate all personnel from the petrol station and restaurant as well as a large group of onlookers that had gathered on the motorway bridge.

Just before the explosion a shrill hiss was heard from the tanker and the fire flared up, so the decision was taken to increase the intervention area to two hundred metres. When the firefighters had withdrawn to this new safety distance the tanker exploded. Some of the emergency team report hearing a detonation behind them; instinctively they turned round and saw a huge burning mass rising and rushing towards them. During a brief space of time they felt intense heat while running off to protect themselves.

After the explosion the tanker broke up into several chunks and scattered fires broke out in a small orchard on top of the embankment and in various zones of scrubland around the tanker. The fires were extinguished without further mishap. At 10:05 hours the driver's body was recovered from the vehicle and the emergency was declared to be at an end at 10:52 hours.

Figure 4. Moments after the explosion. Fire outbreaks. Source: On-the-spot witness.

Leak of contents. Probable causes

The fire was fierce right from the start since all combustible elements of the cab, wheels and vehicle fuel quickly caught fire, totally enveloping the centre of the tanker. After these items had been burnt off, the density of the smoke fell appreciably and the total destruction of the shell came to light, except for the back end; the fire was by now reduced to two huge plumes, one in the central part and another in the righthand rear of the tanker, as shown in the following photographs. Nonetheless, it could in fact be a case of a single fire source broken up into two by a rebound effect from the underneath part on the road and embankment.

Figure 5. Fire in the initial moments and before the explosion. Source: On-the-spot witness.

It seems unlikely that a fire of this magnitude would break out due to the crash alone, since no item of the vehicle has a flammability rating to account for this. The only extremely flammable component was the cargo, so it seems more likely that the crash caused a leak in the tanker’s load; subsequent friction or the vehicle’s engine or a similar cause would then act as ignition source. This chimes in with the reports of several eye witnesses, declaring that they heard “*a sort of loud hiss*”, as well as the diverse tanker fragments found around the flat-bed lorry and the ignited plumes. Several possibilities have been put forward as the cause of the leak. As well as the cab the central part of the tanker also crashed into the parked flat-bed lorry. This central part houses the loading and unloading devices, safety valves and level gauges. A large part of the blue cabinet containing the abovementioned devices was found very close to the flat-bed lorry. This would seem to show that the valve-containing part suffered a collision, with resulting damage to some of the pipelines.

Figure 6. Remains of the tanker’s lower central cabinet (blue fragments to the left). Source: On-the-spot witness.

The remains of the cab show huge deformations on the righthand side, indicating the scale of the impact. It looks as though the cab jack-knifed round completely and dragged along the whole flat bed and cab of the parked vehicle, the cab itself then rebounding in turn against the cabinet, either directly or indirectly. This could be the reason for the breakage of the fastening elements of the concrete sheets, anchored to the side of the flat bed. Another possibility is that some the pipelines were cut by the crash-barrier posts when the tanker lurched into the ditch.

What seems to be totally ruled out, even though this working hypothesis was considered at first, is perforation of the tanker from the crash against the back corner of the flat bed. If so there would be remains of the shell and insulation on the back part of the broken-down lorry and no such evidence has come to light. Moreover, all the photos studied show clearly that the leak was located in the lower central part. In any case these hypotheses are not mutually exclusive; the combined effect of several of these causes might have broken some of the pipelines not fitted with inner gas-tight valves, producing a leak of the cargo.

Characteristics of the road tanker

There are currently two types of ADR-approved LNG transport road tankers: firstly, lorries with a double-walled stainless steel tank and perlite and vacuum insulation, and, secondly, single-walled steel tanks with polyurethane insulation and aluminium outer shell. The road tanker involved in this crash was of the latter type; its characteristics are summed up in the following table.

Table 1. Characteristics of the road tanker. Source[3]

Magnitude/Element	Figure/ Description
Total length	14 metres
Total width	2.6 metres
Inside diameter	2.34 metres
Height	3.8 metres
Rated volume	56,500 L
Test pressure	9.1 bar
Service pressure	7 bar
Service temperature	+50 / –196ºC
Material of the inner body	Stainless steel 304LN
Gauges of the inner body	4 mm cylindrical shell / 6 mm tank ends
Interior baffle plates	Seven 3-mm units
Insulation	130 mm injected polyurethane
Outer vessel	2-mm gauge aluminium / polyester tank ends
Safety valves	Three. Two rated at 7 bar and one rated at 9.1 bar

The whole loading and unloading system and the safety and level elements are housed in the lower central part of the tanke inside a protective cabinet. The valves and pipelines are the following:

- **Loading and unloading connections.** Two of liquid phase and one of gaseous phase. They are fitted with a double valve, one manual and another plug valve inside the tank worked by a pneumatic device

Figure 7. General view of the set of valves and pipelines. In the foreground, the loading and unloading connections . The righthanc photo shows a detail of the inner plug valves. Source(4): Authors.

- **Safety valves.** It is fitted with three safety valves, two rated at 7 bar and one at 9 bar. They link up with the gaseou phase by means of an immersion tube running the whole length of the tanker under the lower insulation and coming up through the front end to connect up with the storage tank. The outlet of the safety valves communicates with anothe tube that rises up flush with the tanker at the centre (always beneath the insulation) and then runs back along the top to the rear, where it relieves excess pressure through a venting device

Figure 8. Safety valves and venting device. Source(4): Authors.

- **Emergency emptying valves.** These are two manual valves each connected up to a pipeline running in opposite directions alongside the inner part of the tanker wall. They rise to a height just above half of the tank and are fitted with siphons at each end. In the event of a 90º or 270º overturn, there would always be one end in the liquid phase and one end in the gaseous phase, allowing for emergency emptying.
- **Maximum filling valve.** This is a siphon tube running up through the inside the tanker to the maximum filling height (85% of full capacity). A manual purging system indicates if the liquid level is above permitted limits.
- **Level control.** This device connects the liquid and gaseous phases to pressure-measuring devices; it calculates the filling level in relation to the liquid's hydrostatic pressure and the inside tanker pressure.

Of all the abovementioned devices and pipelines only the loading and unloading connections are fitted with inner seat valves guaranteeing tank gas-tightness; in the event of any breakage in pipes connected up to these valves, any leaks would be blocked off from inside. Although it seems obvious that the tanker's cabinet area struck the parked flat-bed lorry, as shown by the remains of this cabinet on the road surface, the available photos do not allow us to ascertain the state of these valves since this part of the inside of the tanker is not shown. Nonetheless, this hypothesis seems less probable than breakage of another pipeline not fitted with plug valves.

Historic precedents of lng accidents

A recent study(5) showed that, of the 89 BLEVE-producing, hazardous-material accidents around the world in the period running from 1926 to 2004, only one (Tivissa) involved an LNG road tanker with post-accident ignition of its load. In Spain several LNG road-transport accidents have been reported recently.

Table 2. Natural gas road tanker accidents in Spain. Source(4): Authors.

Year	Place	Consequence	Victims	Accident type 1
1999 (27/01)	Seville	Fire of tanker tyre	-	4
2000 (10/10)	Jabugo (Huelva)	Tanker overturn	-	2
2002 (12/06)	Beas (Huelva)	Tanker overturn	-	2
2002 (22/06)	Tivissa (Tarragona)	BLEVE Forest fire	Death of the driver	5
2002 (04/12)	Huelva	Tanker overturn	Slight injuries to driver	2
2004 (24/03)	Jabugo (Huelva)	Tanker cab fire	-	4
2007 (11/10)	Algodonales (Cádiz)	Overturn with spill	Death of the driver	3
2008 (19/08)	Reolid (Albacete)	Overturn with leak	Death of the driver	3
2010 (25/10)	Sanlúcar la Mayor (Huelva)	Leak through the valves	-	3
2011 (20/10)	Zarzalico (Murcia)	BLEVE Scrub fire	Death of the driver	5
2011 (27/10)	Ribarroja (Valencia)	Overturn without leak	-	2
2011 (21/11)	Palos (Huelva)	Reach of empty LNG tanker	Driver seriously injured	2
2012 (14/01)	Puerto Lumbreras (Murcia)	Overturn of empty road tanker	Driver seriously injured	2
2012 (17/01)	Puerto Lumbreras (Murcia)	Overturn of empty road tanker	-	2
2012 (24/01)	Huelva	Overturn of road tanker	-	2

Accidents type 3 to 5 are the most hazardous and those that pose the biggest risk to the public at large and emergency team. In these cases the intervention will be limited, basically, to rescue and evacuation. Types 1 and 2 call for constant monitoring of the pressure and temperature readings inside the tanker due to its cryogenic load.

Effects of the explosion

The effects of the Zarzalico explosion correspond with those recorded in the BLEVEs documented to date, judging from the literature consulted(6,7,8). According to the specialists most BLEVEs occur when the recipient contains between 1/2 and 3/4 of the total liquid volume. The occurrence of a BLEVE in a recipient, depending on the exposed mechanism, produces the following effects.

- A) **Overpressure blast wave.** This is produced by the shock wave of the boiling liquid expanding vapour. It may be substantial, causing damage and harm to people and property. The pressure wave on this occasion was big enough to cause considerable material damage at a distance of up to 160 metres. This observed overpressure blast wave also seems to tally with the specialists' forecast BLEVE values.
  One of the determining factors of an overpressure blast wave is the location of the tanker in relation to the surrounding lie of the land. The tanker was very close to a 10-metre motorway embankment. This bank acted as a parapet bouncing back the shock wave southwards and causing appreciable damage to the petrol station and its surroundings.

  The petrol station's inner roof slats were warped and torn off on the western side, taking the A-91 in the direction of the accident as east-west reference. Cracks also appeared in the wall of the petrol station building.

  The petrol station windows, seals included sometimes, were blown inwards. There was widespread breakage of glass. In the motorway services area the false ceiling is made of plasterboard panels mounted on aluminium rails. Some of them were raised by the shock wave. Cracks, without any structural ramifications, also appeared in the column covering. Judging from the 80% glass breakage the overpressure blast wave is estimated to have had a maximum value ranging from 0.03 to 0.04 bar.

  Lastly, a lampost with a column height of about 15 metres, standing near the petrol station at a distance of 170m from the explosion, was bent 25º out of true.

Figure 9. Petrol station damage caused by overpressure blast wave. Source(4): Authors.

- B) **Thermal radiation.** The intensity of the thermal radiation received by any living being within the field of influence of a fire depends on the weather conditions (relative humidity), the geometry of the fire (diameter of the fire base height of the flames and distance to the irradiated point) and the physicochemical characteristics of the products in combustion. Radiation giving rise to thermal effects in its interaction with the burning material occurs in the ultraviolet, visible and infrared wave bands.

Radiation is the most devastating effect of a BLEVE. The following estimations have been made of the Zarzalico explosion.

Table 3. Magnitude of the Zarzalico explosion. Drawn up by the authors. Source[9]

Hypothesis	Diameter of fireball (m)	Thermal irradiation (kW/m2)	Duration BLEVE (s)	Height of fireball (m)	TNT Equivalent (kg)
a) The whole cargo explodes (21,580kg)	166,0	132,2	11,0	124,5	9.190,1
b) Half the cargo explodes (10.790 kg)	132,5	79,1	9,2	99,3	4.599,5

The observed on-the-spot effects of the thermal radiation in the Zarzalico explosion seem to bear out these calculated distances. The wooden items of a container standing 141 metres from the road tanker caught fire, showing that an intensity of 12.5 kW/m^2 was reached at this point. By way of example, an intensity of 4 kW/m2 causes bodily pain to anyone unable to reach protected areas. This was not recorded at Zarzalico, where the radiation reaching the people was about 1.6 kW/m^2.

One of the eye witnesses standing 600 m away records feeling a blast of hot air, tolerable but clearly perceptible.

According to J.E.E., fire broke out all around after the explosion. This is confirmed by the burn marks in the terrain revealing the spread of small scrub fires, especially on the hard shoulders of the service road and the central reservation of the motorway. Olive trees and their fruit, growing at 110 metres from the explosion point were affected, as shown in the following photograph.

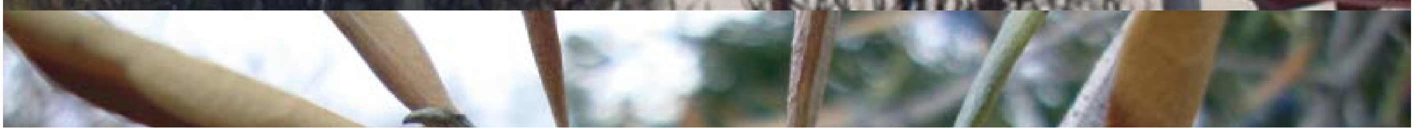

Figure 10. Radiation damage to a road sign and olive tree. Source[(4)]: Authors.

In the Zarzalico accident, although the petrol station, its surroundings and the motorway-cutting in both directions were all evacuated, two people were only a few metres from the site at the moment of the explosion. One of them was driving a car along a country path towards the service road and the other was sleeping overnight in a refrigerated lorry at the petrol station. Neither of them came to any harm since the vehicle cabs in both cases maintained life-compatible conditions. Without any doubt the fact that their windows were closed saved their lives.


Figure 11. Radiation marks on a nearby vehicle. Source[4]: Authors

Flying shrapnel. In explosions of this type fragments are usually large and few and far between. They are sometimes thrown great distances, 1000 m or more (as occurred in 1984 in Mexico City and in the accident of Romeoville, Illinois, in this same year). It is calculated that tanker fragments might be thrown to a distance of about 4-6 times the radius of the fireball and in some cases up to 15R. As pointed out beforehand, the road tanker broke up into three large chunks on the roadway, due to the barrier effect formed by the embankment and the central reservation of the motorway.

The following illustration shows, within the yellow circle, the highest intensity of the fireball's thermal radiation, while the white circle ring-fences the shrapnel distance. The pentagonal figures in white represent the seven baffle plates that were contained inside the tanker. The spatial projection of the tanker is shown in the red-and-white gridded area with the tanker itself in the middle. The petrol station appears in the upper left.

Figure 12. Radius of action of the explosion and zone in which the baffle-plate shrapnel fell: Authors. Source[10]

One baffle plate struck the front part (edge) of the corrugated sheet roof of the petrol station car park, standing about 15(metres from the tanker.

Two of the baffle plates remained beside the tanker, as shown in the following photograph. Another crossed the roadwa) and struck the ditch on the other side.

Small vehicle fragments were collected at a distance of 200 metres from the tanker.

Figure 13. In the foreground, two of the baffle plates of the road tanker. Source: On-the-spot witness.

Action guidelines for dealing with lng tanker fires.

There are certain circumstances in which the first action taken should be evacuation of the population. These circumstances are the following: when the rescue lacks priority (for obvious reasons); when the recipient containing the cryogenic and flammable gas is immersed in a plume of fire caused by the escape of the cargo that is burning in the de-shelled tanke (now bereft of its insulation) and inner pressure is betrayed by the continual release of gas from the venting device. Some of the reasons for this are as follows:

Time
Most BLEVES occur within the first 10-15 minutes of the tanker fire breaking out. The fact that the burning leak was in the liquid part of the tanker is perhaps why the Zarzalico explosion took longer. If the venting device has begun to release ga: continually, the pressure inside is critical and the zone must be abandoned immediately.

Cool down or heat up?
Under these conditions, the use of deluge guns for cooling purposes exposes the emergency team to an unnecessary risk, fo two reasons. Firstly, water applied to a de-shelled cryogenic tanker "heats up" the liquefied natural gas. Applying liquid at a temperature of 200ºC to a surface at 20ºC would not cool down that surface. The same goes for spraying water at 20ºC on a substance at a temperature of -160ºC. Such an action might inadvertently increase the internal pressure and accelerate the BLEVE process. Strictly speaking, if water is played onto the tanker this only cools down the insulation; again this is useless When the insulation has been affected, it is then possible for the water to come into contact with the LNG-containing meta wall, vaporising a greater amount of the liquid.

Cooling down the tanker makes sense only when the outer shell is intact and the fire stems from an external heat source. I this case experts estimate that a flow of at least 10 litres a minute for each square metre of tanker is necessary. Taking the tanker area to be equal to: $A = 2\pi\ (r^2 + rh')$ (ignoring the dished shape of the tank ends), then for a radius of 1 m and a lengt of 13 metres, A comes out at 88 m^2. Water cooling would therefore call for a flow of at least 880 litres per minute. If it i: not possible to achieve this constant flow, cooling should not be attempted. The flows are beyond the capacities of a fire fighting service likely to arrive first at an accident site of these characteristics.

The second reason is that, however far firefighters stand from the tanker, the maximum reach of a jet of water projectec by a deluge gun, in a best-case scenario, is about 50 metres. A due assessment would therefore have to be made of whethe it is worth running the risk of exposing firefighters so close to the accident site. Moreover, at this distance most of the water projected over the tanker would disperse before reaching it, so it would also fall short of its objective.

Another factor that should be borne firmly in mind here is that projecting water over the pressure relief valve on the uppe part of the tanker would run the risk of freezing it, thereby blocking it and increasing the safety risk.

Extinguishment?
Moreover, if application of the water aims at extinguishing the burning leak, it should also be borne in mind that water i: the least effective agent for putting out a gas fire. The huge risk posed by getting to the point of the leak itself to try tc extinguish the flames, together with the risk of freezing in the case of putting it out, rule out this possibility. In such a case a non-burning gas cloud would be generated (remember that the vapour comes out at a temperature of -160ºC and is 1. times heavier than air); this could give rise to an UVCE (Unconfined Vapour Cloud Explosion).

Evacuation
It is therefore clear that the only really effective and realistic action to be taken against a problem of this scale is tc evacuate the population from a wide radius and locate the emergency teams in the most favourable area, in relation to the tanker, and upwind.

As regards the best location in relation to the tanker, taking up a position behind any of the tank ends is the worst option Nonetheless, it will be the lie of the land that dictates the lay out of the emergency team. For self protection purposes it i: considered that the minimum safety distance to be maintained by a fully kitted out firefighter should be 4R (where R is the theoretical radius of any fireball), i.e., 4 x 83 = 332 metres. In any case it is recommended that the distance should be nc less than 100 metres.

The minimum distance to evacuate the population, according to the experts, is about 15R, i.e. 15 x 83 = 1245 metres.

Conclusions

The following conclusions can be drawn from this accident:

1. The first action to taken when confronting an LNG road tanker with its load on fire will be to rescue people anc evacuate the surrounding population. Fire extinguishment should be attempted only when the fire is external to the

tanker and can be tackled with sufficient means. As for the rescue of persons, in most cases the time the tanker has been burning is unknown, so a due evaluation needs to be made of the risk run by rescuing people. The situation is highly complex; if there are any persons trapped, any attempt to free them must be made in hostile and therefore time-consuming conditions (in default of any resources for extinguishing the fire). This might result in many victims. It should be remembered here that emergency teams tackle these accidents with the aim of controlling them and mitigating their consequences. Quite possibly, as in Zarzalico, there is hardly time for a rapid reconnaissance and rescue operation. The population should therefore be evacuated to a sufficient distance, outside buildings. Crouching down behind objects at lesser distances than the established safety distances does not guarantee protection, as is shown by situations of this type.

2. Seek help in carrying out the evacuation and healthcare assistance in prevention activities. Delegate evacuation and traffic cut-off duties to the security forces as far as possible as soon as they turn up on the site.
3. Inspect all possible sites that might contain people or from which they might reach the accident site, however unlikely this may seem. In this accident, unbeknown to the rescue workers, one person was sleeping in the vicinity of the accident site and another was allowed to drive by without restriction of access. The former was not evacuated by oversight and the latter accessed the site from an unsuspected route.
4. Last but by no means least, urge the competent authorities to dictate that liquefied natural gas should always be transported in double-walled road tankers, for greater safety, or, in the case of single-walled tankers, ensure that there are no pipelines directly communicating the liquid and gaseous phases with the exterior, lacking any additional cut-off device in the event of accidental sectioning.

BIBLIOGRAPHY

1. Instituto Geográfico Nacional. Visor de mapas topográficos (IBERPIX map viewer)
2. Víctor Sanz and Juan Francisco Valera.
3. Ros Roca Indox Cryo Energy S.L.
4. Belmonte Pérez, J., Bonilla Martínez, J.M.; Marín Ayala, J.A.
5. Tasneem Abbasi, S.A. Abbasi. The boiling liquid expanding vapour explosion (BLEVE): Mechanism, consequence assessment, management. Journal of Hazardous Materials 141, 2007, p489–519.
6. F.P. Lees, Loss Prevention in the Process Industries-Hazard Identification, Assessment, and Control, vols. 1-3, Butterworth-Heinemann, Oxford, 1996.
7. E. Planas-Cuchi, N. Gasulla, A. Ventosa, J. Casal, Explosion of a road tanker containing liquefied natural gas, J. Loss Prev. Process Ind. 17, 2004, p315–321.
8. J.E.S. Venart, Boiling liquid expanding vapor explosions (BLEVE); possible failure mechanisms and their consequences, in: Proceedings of the IChemE Symposium Series No. 147, 2000, p121–137.
9. J. M. Santamaría and P. A. Braña. Análisis y reducción de riesgos en la industria química. Editorial MAPFRE. Madrid, 1994.
10. Google Inc. Visor Google Earth.