Incident

Buncefield: Lessons learned on emergency preparedness

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Summary

Early on Sunday 11 December 2005 a gasoline storage tank was being filled from a pipeline at a fuel terminal at Buncefield. Safety systems fitted to prevent the tank overfilling failed and gasoline began to spill from the vents on the tank roof. A low-lying cloud of heavy, flammable vapour accumulated and spread out for about 250m in all directions around the tank. Ignition of the cloud occurred and a powerful vapour cloud explosion devastated the fuel depot. The ensuing fire spread to other tanks and was not fully extinguished for several days. Many nearby businesses were forced to relocate for months or even years causing serious commercial losses.

This paper considers the lessons learned related to emergency preparedness at large flammable sites as a result of this incident. These include the responsibility of the operators of fuel depots, tanker terminals, etc. Examples include: risk assessment, prevention of spillage, detection and shut-off, bunding of tanks, provision of fire water and tertiary containment of fire effluent. However, some of the more fundamental lessons are still being assimilated — for example, the potential for severe explosions in open areas is still not widely used as a basis for safety planning.

Perhaps the most important lesson of all was that our view of the range of hazards faced by large flammable sites was seriously deficient. The high levels of confidence that we had a complete working understanding of flammable risks was not justified. Such attitudes are always dangerous and it is an important responsibility for those with a stake in controlling major flammable risks to be open about this.

Keywords: Emergency preparedness, Buncefield

Introduction

Early in the morning of Sunday 11 December 2005 a gasoline storage tank was being filled from a pipeline at a fuel terminal at Buncefield, some 40 km northwest of London. The tank had safety systems fitted to prevent overfilling, but they failed to operate and gasoline began to spill from the vents on the tank roof. Crucially this occurred in nil-wind conditions and a low-lying cloud of heavy, flammable vapour accumulated. The gravity-driven cloud spread out for about 250m in all directions around the tank. After 25 minutes the overfill was discovered and the site emergency system was activated at 06:01; unfortunately this involved starting the site firewater pump which was located within the cloud. Ignition occurred in the pumphouse and a powerful vapour cloud explosion devastated the fuel depot. Twenty storage tanks containing gasoline, aviation fuel and diesel were immediately set on fire. The fire subsequently spread to two additional tanks and was not fully extinguished for several days. The fire-fighting operation is described in more detail in the second half of this article. A good introduction to the underlying causes and significance of the incident has been published by the Competent Authority Strategic Management Group[1].

The blast effects caused catastrophic damage to all of the areas, both on and off-site, that were covered by the cloud: all of the buildings, tanks and plant in this area had to be completely cleared. Commercial and residential premises within about 100m of the edge of the cloud also suffered serious structural damage and several had to be demolished. Lower levels of blast damage affected many commercial buildings within about a kilometer from the site: damage was typically to the cladding and weather-sealing of these large buildings (Figure 1). Although the damaged cladding could be replaced, the scale of this work meant that many businesses were forced to relocate for months or even years causing serious commercial losses.

This paper reviews the emergency response to the incident and the lessons learned for the future. Two types of issue are considered:

1. Emergency preparedness: these issues are mainly the responsibility of the operators of fuel depots, tanker terminals, etc. Examples include: risk assessment, prevention of spillage, detection and shut-off, bunding of tanks, provision of fire water and tertiary containment of fire effluent.
2. Emergency response: these issues are mainly for the Fire and Rescue Services (FRS). Examples include: incident control, regional/national deployment, foam management, effluent control etc.

Reports on the incident and associated recommendations

Several significant studies of the incident have been published and their findings and recommendations have formed the basis for change in the UK.

Major Incident Investigation Board[2]

This report included recommendations in several areas:

- High integrity overfill protection (ten recommendations);

knowledge and competence

systems and procedures

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Figure 1 – Damage to a warehouse 400m from the overfilled tank (Copyright: HSE)

- Engineering against escalation e.g. zoning, detection, overflow systems (six recommendations);
- Secondary and tertiary containment issues (two recommendations);
- Human factors, culture and leadership (seven recommendations);
- Control of land use and risk around major hazards sites (18 recommendations);
- Emergency planning (32 recommendations) – this heading included recommendations on:
  - On and off-site planning (and testing of plans);
  - Siting of critical emergency infrastructure;
  - Interfacing site and FRS resources;
  - National co-ordination of response to major incidents by FRS, Health Services, Environmental Protection Agencies;
  - Economic and environmental recovery planning for areas with major hazard sites.

The Process Safety Leadership Group[3]

This group was designed to meet the need for an effective framework for interaction between industry and the UK government to jointly develop and implement effective recommendations and practices for fuel storage sites. Their final report provides detailed guidance in a number of areas, for example: the use of Layers of Protection Analysis (LOPA) to determine appropriate safety integrity levels (SIL) for over-fill protection systems, the design of fire resistant bunds and the identification of materials (other than gasoline) that can form large vapour clouds if tanks are overfilled.

In some areas the PSLG did not support the adoption of recommendations made by MIIB; for example, the use of vapour detection at fuel storage sites and the fitting of overflow pipes to eliminate vapour cloud production if tanks were overfilled. The PSLG report also recommended that in planning fire-fighting the appropriate worst case design fire for a fuel depot should be assumed to be fire in a single bund. Several incidents in fuel depots both before and after Buncefield have clearly demonstrated that this is not appropriate. The PSLG approach was based on an old code of practice published by the Energy Institute[4]. More recent editions of this code[5] draw attention to the fact that multi-bund fires (like Buncefield) can occur at fuel depots.

Hertfordshire Fire and Rescue Service report[6]

This report focussed on the practical firefighting experience gained by the local fire brigade in dealing with Buncefield. A number of recommendations are made in the areas of:

- fire fighter health, safety and welfare;
- incident command;
- national deployment of resources;
- equipment (especially compatibility issues);
- gathering and managing foam resources.

Scientific studies

The incident has prompted a large amount of new experimental, analytical and review work addressing the issues of:

- vapour cloud formation during overfilling incidents[7, 8];
- flame acceleration in congested environments[7];
- blast effects from extended low-lying vapour clouds[7];
- explosion effects on common objects- vehicles, drums boxes, etc.[7, 9];
- explosion effects on tanks and buildings[10].

A practical method of assessing the volume and fuel concentration of the vapour cloud caused during overfilling is now available[8] and is increasingly used in risk assessments and emergency planning for fuel depot sites.

However, the problem of explosion mechanics remains substantially unsolved. Based on forensic evidence at the scene there is near universal agreement that high (>2000 mbar) overpressures were observed across the whole cloud area at Buncefield and in other more recent incidents[11] but the nature of these explosion events, and the circumstances that triggered the transition to a severe explosion rather than a flash fire, remain a subject of active investigation and debate. A review of historical vapour cloud explosions[9] revealed a number of very large (>200 m radius) severe gasoline vapour cloud explosions like Buncefield but *no* equivalent flash fires. Notwithstanding the lack of pressure effects, such flash fires could cause deaths or injuries and would certainly leave a huge burned area. It seems likely that a high proportion of such occurrences would

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be reported and the lack of such reports suggests that if a very large cloud develops at a gasoline fuel depot the probability of a severe explosion is high. The features that lead to transition from a flash fire to a severe explosion must be common features of most sites. Consequently it is reasonable to assume that if a large gasoline vapour cloud accumulates at a fuel depot then ignition will cause a severe explosion. This is fundamental to the proper definition of requirements for emergency response e.g. assessment of blast effects from incidents and the potential for widespread tank fires.

Emergency preparedness

Risk assessment

Buncefield and similar recent incidents have had a profound effect on our understanding of the potential consequences of loss of containment at gasoline fuel depots and many other large flammable sites. It was immediately apparent from CCTV views of the smooth topped vapour cloud that the incident occurred in nil-wind conditions. At first this was regarded simply as a coincidence that perhaps somewhat increased the reach of the cloud. More recently, a review of the history of all large flammable vapour cloud incidents (including gasoline, LPG and other fuels) has shown that more than 70% of all such incidents occur in nil-wind conditions[9]. At first sight this is a surprising result since such conditions are relatively rare (<5% in the UK); it can however be understood when one appreciates that the area covered by the flammable cloud in nil-wind conditions is typically hundreds of times greater than for the *same release* in light winds and the probability of ignition is correspondingly greater.

If a tank like that at Buncefield is overfilled in normal (windy) condition the vapour cloud is generally confined to the area close to the tank and the probability of ignition is extremely low. In the aftermath of Buncefield it was noted by many in the fuel supply industry that overfilling of tanks was not uncommon, but incidents like Buncefield certainly are. It is now possible to explain this observation: the formation of large vapour cloud with a high risk of ignition only occurs in nil-wind conditions. In the vast majority of overfilling incidents the vapour is dispersed by the wind without ignition. Similar comments apply to very large vapour clouds such as those at Jaipur and St Herblain that were caused by gasoline spray releases in nil-wind conditions[12, 13].

The observation that ignition of such very large gasoline vapour clouds have generally produced severe explosions further focusses the risk assessment for liquid fuel depots. There have been a number of incidents that closely correspond to Buncefield and no other sort of incident has caused comparable widespread damage to the site and surroundings. What happened at Buncefield is not just a contributor to the total risk of a major incident at fuel depots, it *dominates* the risk of a major incident. It should be the focus of emergency planning. This has been recognised by HSE and the specification of planning zones around gasoline terminals[14] is based on Buncefield-type incidents (only).

The situation for sites handling larger quantities (>25 tonnes) of LPG is less clear. There is a parallel history of large vapour cloud incidents in nil-wind conditions[9] but the high fuel volatility means that in this case some over-rich flash fires have also occurred. Some other types of major incident are possible for LPG — for example, BLEVE of a strong fuel tank may produce dangerously high thermal doses to people exposed at significant distances, but it is still only VCEs that can produce widespread damage to people in buildings and infrastructure.

Prevention of spillage

The importance of high-integrity protection against overfilling is well documented by the MIIB and PSLG reports[2, 3]. It should be noted that spray releases (especially those directed upwards) have also caused very large vapour clouds (radius >400m) with a similar explosion signature to Buncefield. Such spray releases have occurred in pumped systems and in leaks driven by hydrostatic pressure.

Detection and shut-off

Different approaches to mitigation may be appropriate when nil/low-wind scenarios like Buncefield are considered. For example, detection of gas plumes in windy conditions generally requires a large number of closely spaced devices and the chances of limiting maximum cloud size and risk of ignition by shut-down are low because the cloud normally reaches its maximum size very quickly (< 100 seconds). Investment in detection systems may not be warranted. On the other hand, in nil/low-wind conditions the cloud develops slowly and can be reliably detected by a small number of sensors. Shut-down on detection may be a key element of a site's safety planning.

Bunding of tanks

There was widespread loss of secondary containment (bund integrity) on the Buncefield site. While the bunds remained standing throughout the incident, their ability to fully contain the fuel and fire waters was lost as a result of the prolonged fires. Sealant used as infill between concrete panels was not protected and was displaced by the fire in many places. Large leak paths were also opened up by thermal stresses that caused the concrete bases of bunds to heave and crack. The PSLG report[3] provides good advice on improving performance covering bund lining systems, expansion and contraction joint design and protection of joints and pipe penetrations.

Emergency response

Initial response

Fire and Rescue Services across the South-East of England received more than 200 emergency calls after the explosion and more than 50 calls from automatic fire alarm systems — a wide range of locations and causes were cited in the calls. Nevertheless the Hertfordshire FRS reached the site within about five minutes, where they encountered workers from the depot suffering from blast injuries and shock.

Initially there were six persons on the site who were unaccounted for near the west loading gantry and initial FRS work focused on searching wrecked buildings in this area. The work was impeded by tank top and cylinder explosions that cause further damage to weakened buildings as they were being searched. Some employees remained at the site and activated emergency plans; they provided the FRS with a map of the site and advised crews. It took six hours to search accessible parts of the site and a large number of blast

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damaged commercial and residential properties surrounding the site.

Debris blocking roads meant that crews could not access large parts of the site perimeter to assess the full extent of the fire. A police helicopter attended from 6:46 am but the Fire Incident Commander could not access these pictures. Eventually a FRS officer was taken up shortly after 9:00 am and was able to report back to the command team on the full extent of the incident.

Early fire firefighting

The FRS dealt with smaller fires in office buildings around the site, but until midday on 11/12/2005 the tactical mode of on-site operations remained defensive (Figure 2). Some hoses for cooling jets were laid around the site perimeter and foam calculations were carried out for attack on the main fire. Local stocks of foam were nowhere near sufficient to allow an attack on the main tank/bund fires. Within an hour of the explosion the FRS had contacted the main UK supplier of fire-fighting foam to discuss mustering national stocks of foam concentrate.

A one million litre water supply was immediately accessible in the north-east part of the site. From shortly after midday this water was used (at about 600,000 litres per hour) for cooling jets to protect road tankers near the gantry, unaffected tanks in Bund D and other unaffected parts of the site. Lack of water and safety concerns about tank collapse led to withdrawal after about two hours.

The first foam attack was made at 17:00 on 11/12/2005 on a rim seal fire in a tank on the eastern edge of the tank farm fire. Semi-fixed foam pourers were used but the attempt was aborted because of concerns that the floating roof would sink. At 21:00 a successful foam attack was made on a tank on the southern edge of the fire.

Main foam attack

In preparing for attacking the main fire the command group made the following assumptions:

1. Fire size 100 x 100m
2. Foam application rate 8 litres per minute per m^2
3. Concentrate/water ratio 3%
4. Time required 1 hour

This analysis suggested 150,000 litres of concentrate would be required — which was doubled to 300,000 litres to provide a margin for error and allow for foam blanket maintenance. In practice extinguishing the main fire took about 60 hours and required 786,000 litres of concentrate with 53 million litres of clean water.

On-site water supplies represented less than 2% of total water requirements and the bulk of fire-fighting water was taken from a balancing tank at a distance of about 1.9 km from the site. This required the laying of hardcore as a temporary road to allow installation of High Volume Pumps. A sufficient water supply to support the main attack took more than 24 hours to set up.

The main attack started at about 08:30 on 12/12/2005 (explosion + 25.5 hours). The final ignited tank collapsed and allowed control to be established at about 07:00 on 14/12/2005 (+73 hours). The fire-fighting effort met with a number of difficulties:

1. Rapid re-ignition of bund fires – requiring fresh blanketing every 15 minutes;
2. Running fires caused by bund overtopping;
3. Uncertainties about the structural integrity of badly damaged tanks;

Figure 2 – Photograph taken at 10:40am 11/12/2005 (4.6 hours after the explosion) (Copyright Chiltern Air Support). The photograph shows the main bund fire. The explosion has also caused a fire in the office building in the bottom left corner

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Figure 3 – Photograph taken at 15:47pm 13/12/2005 (57 hours after the explosion) (Copyright Chiltern Air Support). The photograph shows residual tank fires: Tank 912 (top right) still has a substantial inventory.

4. High ground level smoke concentrations as the heat release was reduced;
5. Flange fires that could not be isolated at the foot of tanks with high initial inventories (Figure 3).

The fire was declared to be "ALL OUT" at 12:30 on 15/12/2005 (+102 hours Figure 4). Many nationally mobilised resources were released in the evening of 16/12/2005. Foam application (to maintain blanketing) was halted at 10:40 on 17/12/2005 but there was a re-ignition soon afterwards. A permanent FRS presence on the site was required until 5/1/2006. Freezing temperatures caused hose bursts and affected some appliances.

Removal of product residues commenced on 17/12/2005.

Effluent management

Only 2.5 million litres of firewater retention capacity could be made available by emptying the site waste water reservoir; which corresponded to <5% of the total tertiary containment capacity required. Water was regularly redistributed around various bunds that were available, but many were compromised. Effluent was pumped into bunds on an adjacent fuel depot site but then had to be pumped back when advice on bund integrity changed. A local electrical sub-station was inundated by rising water levels and had to be isolated.

About 22% of the total water used in cooling and foam production was recycled by pumping from bunds. Recycled water was generally used for cooling; with clean water being used for foam production.

Because the amount of tertiary containment available was so small a high proportion of the water and foam applied was lost to local watercourses and groundwater.

Air pollution

Smoke from the fire produced a huge, high-level smoke plume blanketing much of southern England. However, high rates of heat release and relatively low wind speeds led to efficient and sustained plume lift-off for most of the incident; without grounding of the plume at long range. Almost all of those seeking medical assistance for respiratory effects were engaged in fire-fighting operations[15].

Conclusions

The Buncefield incident has had an enormous impact on all aspects of planning for emergency preparedness at large flammable sites in the UK and more widely. Some of the more fundamental lessons are still being assimilated — for example, safety assessments at many gasoline fuel depots now include gravity driven vapour clouds extending to long range but awareness of such incidents is still uncommon at sites handling LPG. Similarly the potential for severe explosions in open areas, illustrated by Buncefield and subsequent incidents, is still not widely used as a basis for safety planning.

Perhaps the most important lesson of all was that our view of the range of hazards faced by large flammable sites was seriously deficient. The high levels of confidence that existed amongst some regulators and industry experts, that we had a complete working understanding of flammable risks, was not justified. Such attitudes are always dangerous and it is quite likely that there will be other incidents with a similar impact in the future. It is an important responsibility for those with a stake in controlling major flammable risks to be open about this.

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Figure 4 – Photograph taken at 12:52pm 15/12/2005 (102 hours after the explosion) (Copyright Chiltern Air Support). The photograph shows rising water levels - due to continued water use and leakage from bunds

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Further reading

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Buncefield: Hertfordshire Fire and Rescue Service's Review of the Fire Response

The explosion and fire at the Buncefield Oil Storage Depot involved 22 tanks. The main fires were extinguished in three days but the overall fire response lasted 26 days and 642 fire appliances were moved to the incident. This report sets out the chronological sequence of events and reviews the fire response.

It covers:

- pre-planning and pre-training;
- the response of the Hertfordshire Fire and Rescue Service;
- the response by other fire provider and supporting organisations; and
- presents the learning points of local, national, and international significance, which are drawn both from good practice at the incident and the areas that could have been improved.

For further information, see https://www.tsoshop.co.uk/bookstore.asp?FO=1296546&DI=616388

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