# BUNDING AT BUNCEFIELD: SUCCESSES, FAILURES AND LESSONS LEARNED

Aidan Whitfield[1] and Dr Mike Nicholas[2]
[1]Environment Agency, Kingfisher House, Goldhay Way, Orton Goldhay, Peterborough. PE2 5ZR, e-mail: aidan.whitfield@environment-agency.gov.uk
[2]Environment Agency, Frimley Business Park, Camberley, Surrey. GU16 7SQ, e-mail: mike.nicholas@environment-agency.gov.uk



A large fire that burned for several days and consumed over 40 million litres of fuel followed the explosion at the Buncefield fuel storage depot in December 2005. Fortunately nobody was killed but over 40 people were injured, there was extensive damage to property and pollution of the soil and groundwater. The performance of the tank bunds had a significant effect on fire fighting operations and the extent of the pollution. Some bunds remained intact but others suffered loss of containment during the fire, releasing fuel and firewater containing perfluorooctane sulphonates (PFOS) used in the fire fighting foam. The subsequent pollution of groundwater exceeded the threshold for reporting the environmental impact to the European Union under the Control of Major Accident Hazards (COMAH) Regulations 1999. This paper examines the secondary and tertiary containment systems, focussing on bund designs and the effect they had on the loss of containment.

The paper also describes several other recent incidents that involved loss of secondary and tertiary containment at COMAH sites and how these, together with Buncefield, led to the Competent Authority adopting a containment policy to raise standards across the fuel storage sector.

KEYWORDS: Buncefield, Control of Major Accident Hazards Regulations 1999, COMAH, perfluorooctane sulphonate, PFOS, secondary containment, tank bunds, tertiary containment.

## THE EXPLOSION AND FIRE AT BUNCEFIELD

Buncefield is a major fuel storage and distribution depot located just outside Hemel Hempstead, some 40 kilometres north-west of central London. It was opened in 1968 and is the fifth largest oil depot in the United Kingdom (UK). Fuels are received from the coastal oil refineries via 3 separate pipelines. There are over 35 tanks on the site, ranging from 400 to 19,000 cubic metres capacity, located in 9 concrete and 2 earth bunds. All the tanks are built of steel, above ground, to conventional oil industry standards with fixed and floating roofs.

 

The site supplies aviation fuel by pipeline to Heathrow and Gatwick airports and distributes other fuels by road tanker to local customers. There are 3 operators on the site: Hertfordshire Oil Storage Ltd (HOSL); the British Pipelines Agency (BPA) and British Petroleum Oil (UK) Ltd (BP). Each of the 3 establishments is classified as top tier under the Control of Major Accident Hazards (COMAH) Regulations 1999. A joint Competent Authority (CA) comprising the Health and Safety Executive (HSE), the Environment Agency and the Scottish Environment Agency (SEPA), implements the COMAH regulations in Great Britain.

Just after 6 am on Sunday 11 December 2005 there was a massive explosion at the site, followed by a fire that involved over 20 tanks in 7 separate bunds. A large office building 100 metres beyond the site boundary was also set alight. The explosion injured several members of staff, destroyed the fire-water pumps and severely damaged the site offices so there was no effective fire fighting capability available from within the site. By the end of the day the fire in the office block had been extinguished and the fire on-site had been prevented from spreading to adjacent tanks.

On Monday 12 December 2005 the fire service mounted a plan to extinguish the fire. Large quantities of foam were applied to each tank and each bund in turn to extinguish the fire, then a foam blanket was maintained to prevent re-ignition. By Wednesday afternoon tank 12 at the north end of the site was the only one still alight. “Fire out” was declared on Thursday 15 December.

The subsequent investigation by the CA revealed that the initial loss of primary containment was the overfilling of a petrol storage tank T912, one of 3 tanks in a concrete bund, operated by HOSL. This continued for approximately half an hour and several hundred tonnes of petrol cascaded down the outside of the tank producing a large vapour cloud that exploded as a result of one or more sources of ignition.

The explosion produced overpressures that were much higher than expected and research is being carried out to understand why. The overpressure caused considerable damage to tanks and surrounding buildings.

During the initial stages of the fire, many of the bunds performed well. They contained both leaking fuel and fire-water, which allowed the fire service to operate close to the burning tanks and reduced the escalation of the fire. However loss of integrity of some bund walls developed over the following days, which allowed fuel and contaminated fire-water to flow out over the site. The fire services minimised the impact of this by re-circulating firewater and pumping it into other non-damaged bunds. Despite their efforts, a significant volume of liquid escaped into Cherry Tree Lane, a public highway that runs through the site. It then flowed under a bridge under the M1 motorway, where it soaked into the ground.

Cherry Tree Lane has a number of road drains connected to deep chambers, one of which contains a borehole at least 40 metres deep that penetrates the chalk aquifer. The on-site drains and road drains provided pathways for fuel and contaminated firewater to pollute the groundwater.

The fuels stored at the Buncefield terminal are classified under the Chemical (Hazard Information and Packaging for supply) (CHIP) Regulations 2002 as R51/53 “Toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment". In addition, the fire service applied 68 million litres of water and 786,000 litres of foam concentrate to fight the fire. Some of this foam contained perfluorooctane sulphonate (PFOS) which is persistent, bio-accumulative and toxic. About 33 million litres of fire water run-off were recovered from the terminal and taken off-site in road tankers for treatment and disposal. The operation to remove fuel and firewater from the site and its surroundings continued for many weeks after the fire was extinguished.

## CONTAINMENT SYSTEMS

The safe storage of liquid dangerous substances is achieved by a combination of primary, secondary and tertiary containment systems:

- Primary containment is the most important means of preventing major accidents involving liquid dangerous substances. It is achieved by the equipment that has direct contact with the substances being stored or transported such as storage vessels, pipe-work, valves, pumps and associated management and control systems. It also includes equipment that prevents the loss of primary containment, such as high level alarms linked to shutdown systems.
- Secondary containment minimises the consequences of a failure in the primary containment system by preventing the uncontrolled spread of the liquid dangerous substance. Secondary containment is achieved by equipment that is external to and independent of the primary containment system, such as concrete or clay bunds around storage tanks. Secondary containment will also provide limited storage capacity for firewater management.
- Tertiary containment minimises the consequences of a failure in the primary and secondary containment systems by providing an additional barrier preventing the uncontrolled spread of the liquid dangerous substance. Tertiary containment is achieved by means external to and independent of the primary and secondary containment systems, such as site drainage and sumps, diversion tanks, impervious liners and/or flexible booms. Tertiary containment will be utilised when there is a small scale loss of primary containment from an area without secondary containment (e.g. a pipe flange leak or an overturned road tanker), and when there is a major incident that causes the failure of the secondary containment e.g. bund joint failure or firewater overflowing from a bund during a prolonged tank fire.

## INCIDENT INVESTIGATION

A joint investigation team from the HSE and Environment Agency spent almost a year on the site. The most significant feature of the Buncefield incident was the vapour cloud explosion and it was this that caused the vast majority of the off-site damage to property. The incident investigation therefore focussed most of its effort on the initial loss of primary containment and the mechanism of vapour cloud formation. The key findings relating to the loss of secondary and tertiary containment systems were:

- The bunds substantially remained standing throughout the incident, but their ability to fully contain the fuel and firewater was lost.
- The bund design did not provide for effective fire-water management because there was no means of safely removing fire-water from below the layer of fuel and foam. The fire service reported that one of the bunds eventually filled and overflowed. When this happens it is difficult to predict where the fuel overflow will occur because the top of bund walls are practically level. As the bund reaches its maximum capacity, maintaining the foam blanket integrity can be increasingly difficult because the liquid surface becomes exposed to the wind and the draft of air being drawn in by the fire. Once fires are extinguished, it is important to maintain a foam blanket to reduce the risk of re-ignition and this introduces further quantities of firewater that will require containment.
- Many of the bund walls suffered loss of containment at the pipework penetrations and there was leakage due to the loss of seal between pipes and the bund wall.
- Damaged product pipework provided pathways for liquids to escape from bunds or to flow from one bund into another.
- The performance of the expansion and construction joints between concrete slabs varied between bunds. The joints that performed best had metal waterstops cast into them. The joints that had been modified by the installation of a metal plate in the inside face were provided with some degree of protection. In a number of bunds the joint materials were badly damaged resulting in loss of integrity.
- In at least two locations, the concrete bund floor buckled and broke.
- The tertiary containment systems did not contain fuel and fire-water within the boundaries of the terminal. Loss of power to pumps and inadequate drainage and lagoon integrity and capacity were key contributors to this.
- Although the terminal was located on a layer of clay, which helped reduce the impact of the incident on the underlying chalk aquifer, there were several on and off-site pathways that transported polluting materials directly into the groundwater.

## THE DAMAGE TO PEOPLE, PROPERTY AND BUSINESSES

Fortunately nobody was killed but over 40 people were injured. The explosion caused significant off-site damage to industrial and domestic properties and the fire destroyed one major off-site office block. Residents and businesses had to find alternative accommodation while their properties were repaired. Civil damages claims in excess of £660 million have been lodged.

The tanks and bunds involved in the fire were completely destroyed, along with the offices and road tanker loading bays. They were all demolished and the site cleared down to ground level. The BP Oil tanks in the south-east corner of the site were virtually undamaged and the fuel in them was taken off-site in road tankers for re-refining several months after the fire. BP are planning to restart operations in their part of the depot in 2008.

## THE DAMAGE TO THE ENVIRONMENT

The site is covered with a layer of clay soil approximately 5 metres deep, below which is a chalk aquifer used to supply potable water for the surrounding region. A number of boreholes have been sunk around the site and many groundwater samples have been taken in an attempt to establish the extent and severity of the pollution. The results suggest that groundwater under the site and up to 2 km to the north, east and south-east has been contaminated with hydrocarbons and PFOS. The accident has been reported to the European Union because the area of contaminated groundwater exceeds 1 hectare. The nearest public supply borehole is about 3 kilometres from the site and it has been shut down since the accident. A groundwater remediation plan is being developed. The clean-up is likely to be expensive and will take many years to complete.

## ACTION TAKEN TO IMPLEMENT THE LESSONS LEARNED

Within days of the incident, the government set up the Buncefield Major Incident Investigation Board (MIIB). Their reports have explained the cause of the accident and made recommendations on issues such as design and operation of fuel storage sites, major incident emergency preparedness and work concerning the explosion mechanism.

The investigation board has recommended that the Competent Authority and the sector should jointly review existing standards for secondary and tertiary containment with a view to the Competent Authority producing revised guidance. The review should include, but not be limited to the following:

- developing a minimum level of performance specification of secondary containment (typically this will be bunding);
- developing suitable means for assessing risk so as to prioritise the programme of engineering work in response to the new specification;
- formally specifying standards to be achieved so that they may be insisted upon in the event of lack of progress with improvements;
- improving firewater management and the installed capability to transfer contaminated liquids to a place where they present no environmental risk in the event of loss of secondary containment and fires;
- providing greater assurance of tertiary containment measures to prevent escape of liquids from site and threatening a major accident to the environment.

They also recommended that revised standards should be applied in full to new build sites and to any major modification work at existing sites. They recognised that it may not be practicable to fully upgrade bunding and site drainage on existing sites. In such cases the operators should agree with the Competent Authority a risk-based plan for phased upgrading to achieve as close to new plant standards as is reasonably practicable.

The HSE, the Environment Agency and the oil industry set up the Buncefield Standards Task Group (BSTG) to co-ordinate implementation of the lessons learned. This was particularly effective at identifying and implementing the "quick wins" – a series of relatively simple measures to reduce the likelihood and severity of a Buncefield type accident. Their final report recommends engineering measures to prevent the loss of secondary and tertiary containment, including bund integrity, fire-resistant bund joints, firewater management and risk assessment. The BSTG has now been superseded by the Process Safety Leadership Group (PSLG).

The Competent Authority carried out a review of more than 100 fuel storage sites around the country where a Buncefield type accident could occur. The review was published in March 2007 and identified a significant number of sites that will need to carry out work to bring their primary, secondary and tertiary containment systems up to modern standards. Some of this work has already been completed.

In June 2007 the Competent Authority consulted on a containment policy that sets out the broad principles for determining what the standards should be. For above ground storage tanks containing substances that are flammable, highly flammable or extremely flammable the policy proposed that, in addition to provide secondary containment of the dangerous substance, the bund should have:

- adequate capacity and design to allow fire prevention and control measures to be taken;
- fire resistant structural integrity, joints and pipework penetrations; and
- a means of removing fire-water from below the surface of the liquid in the bund (for dangerous substances which are not miscible with water and have a lower density than water).

## OTHER INCIDENTS

Whilst Buncefield has been the most dramatic and high profile process industry accident in Britain for many years, there have been several other recent accidents involving the loss of primary and secondary containment at fuel storage depots.

### PETROL LEAK AT STRATH SERVICES (OPERATED FOR CONOCOPHILLIPS), MAYFLOWER TERMINAL, PLYMOUTH. JULY 2007

The terminal is a COMAH top tier establishment supplied by ship and distributing unleaded petrol and other fuels to south-west England.

An investigation by the Competent Authority is in progress as at December 2007, so the description given below should be regarded as provisional.

In July 2007, approximately 60 tonnes of unleaded petrol leaked from a hole in the base of a tank over a period of one to two weeks. When the leak was discovered by inventory discrepancy a water bottom layer was placed in the tank while the remaining petrol was transferred to other storage. The petrol leaked directly into the earth base of the bund below the tank and permeated the ground, emerging at a lower level nearby. The tank was due for a full inspection in September 2007.

A Prohibition Notice was issued under the Health and Safety at Work etc Act 1974 stopping operation of the terminal because flammable vapour was detected in the control room. The notice was lifted once the operator had installed preventive measures. A

 

COMAH Improvement Notice was issued requiring the operator to submit bund improvement proposals. The operator has complied so the notice has been lifted.

The reason for the leak is believed to be external corrosion leading to a small hole in the tank sump. The petrol is being recovered from the ground and does not appear to have moved beyond the site boundary.

DIESEL OIL LEAK AT CHEVRON, POOLE HARBOUR. OCTOBER 2006

Chevron operates an oil/fuel storage facility on Poole harbour, supplied by ship and distributing by road to local businesses. It is a COMAH lower tier establishment. There are 6 tanks each of 1,000 tonnes capacity, 3 in one bund and 3 in another. The nearby Poole Harbour is an SSSI and Ramsar site with high amenity value.

An investigation by the COMAH Competent Authority is still in progress as at December 2007, so the description given below should be regarded as provisional.

Approximately 25 tonnes of diesel fuel leaked from a hole in a tank base over several days at the end of October 2006. The fuel escaped into the ground through a defective joint in the concrete bund floor. When the leak was detected, water was added to the tank to float the fuel away from the hole and the remaining diesel pumped to another tank. The majority of the diesel entered a disused trade effluent sewer below the bund and was collected at the sewage treatment works. A recovery sump was excavated and further oil recovered from the sump and onsite boreholes. No oil entered the estuary.

The tank had been inspected 18 months previously and given a certificate for 5 years. Two other tanks in the same bund contained unleaded petrol. All 3 tanks were emptied and two COMAH prohibition notice were served to prevent them being used until the bund has been repaired. The notices are still in effect as at December 2007.

KEROSENE LEAK AT PETROPLUS, MILFORD HAVEN. AUGUST 2005

Petroplus, Milford Haven is a fuel storage and distribution facility mostly using ships and the national pipeline system. It is a top tier COMAH establishment. There are about 80 tanks that can store up to about 1.5 million cubic metres of fuels and were built in the 1960s as part of the Gulf refinery that closed in 1996. Milford Haven is a Special Area of Conservation.

On 2$^{nd}$ August 2005 Petroplus reported a leak of 653 tonnes of kerosene from a 40,000 cubic metres capacity storage tank. A water heel was established in the tank and the contents were transferred to another tank on-site. Kerosene was discovered in gardens, farmland, the foul water sewers, a stream and along the shoreline several hundred metres outside the site boundary. The incident resulted in substantial local concern and media interest. 550 tonnes of the oil was recovered from on-site boreholes and a skimmer was installed to remove oil from the local stream.

The leak was caused by pipework rubbing against the sump in the base plate floor, that had been replaced following a leak in 2001. The kerosene leaked out of the tank and down through the permeable floor of the bund into the ground. It went undetected for several days because it was not visible in the bund and the operators thought there were gauging errors.

 

Petroplus were prosecuted at Haverford West Magistrates court on 10 August 2006 and pleaded guilty to 3 charges; under the Water Resources Act 91 for causing kerosene to be released into controlled waters, under the PPC Act 2000 for breaching a permit condition and under the COMAH regulations 1999 for failure to take all measures necessary to ensure the mechanical integrity of the tank and prevent the accidental release of a hazardous substance into the environment. They were fined a total of £30,000 with £40,000 costs. They have also paid an estimated £3 million in clean-up costs. The pollution of groundwater exceeded the 1 hectare threshold defined in the COMAH regulations for reporting the environmental impact to the European Union.

The site was purchased by SemLogistics in February 2006. They tried to repair the tank that leaked at a cost in excess of £1.4 million, by lifting the tank walls and installing a bentonite mat below the tank. However they could not replace the metal base plate because the walls went out of shape, so they now intend to replace that tank completely. They are developing a programme to improve the tank base containment across the site.

## ENVIRONMENTAL RISK ASSESSMENT (ERA)

The best way to achieve inherent safety is to remove the hazards, but this is not possible at a fuel depot whose prime purpose is the bulk storage of hazardous substances. In such cases multiple layers of protection are required to ensure the risks to people and the environment are reduced to an acceptable level. Detailed guidance on how to carry out an Environmental Risk Assessment (ERA) at COMAH establishments was published by the Competent Authority in 1999.

One of the important tools that can be used in an ERA is the Source-Pathway - Receptor model.

At 3 of the sites described in this paper, underground pathways were a significant contributor to the pollution of the environment:

- At Buncefield there were road drains leading to soakaways and an uncapped borehole on Cherry Tree lane
- At Milford Haven there was a geological fault below the tank through which the fuel leaked downwards rather than spreading out and becoming visible close to the tank.
- At Poole Harbour there was a redundant foul water sewer pipe underneath the tank bund which was still connected to the local sewage treatment works.

On all 4 of the sites there was loss of integrity in the secondary and tertiary containment systems at the time of the incident:

- At Buncefield the integrity and capacity of the tertiary containment (bunds, drains, lagoons etc) was insufficient to prevent releases off-site
- At Milford Haven and at Plymouth the tank bunds had permeable bases that extended under the tanks.
- At Poole Harbour there were defective joints in the concrete bund floor such that the bund was incapable of holding liquid.

 

It is essential that pathways and receptors are properly identified. The secondary and tertiary containment systems should be effective at blocking those pathways, but it must be recognised that loss of containment from these systems may occur during an incident.

## CONCLUSION

Many of the fuel storage depots in the UK were built in the 1950s and 1960s. They were designed to the safety and environmental standards of the day, but since then containment standards have risen. All sectors of industry where bulk liquid hazardous materials are stored need to consider the incidents at Buncefield, Plymouth, Poole Harbour and Milford Haven and recognise the potential for loss of secondary and tertiary containment systems during an incident. It is essential to identify the pathways where liquids may be released and take mitigation measures to reduce the subsequent impact. Whilst primary containment is of the utmost importance, history has repeatedly shown that secondary and tertiary containment systems will be called upon as the last lines of defence. It is vital that containment systems at such establishments are carefully reviewed and the necessary actions are taken to ensure that they meet the standards that pertain in 2008. The actions may be expensive but the costs of off-site environmental clean-up often make them cost effective.

The COMAH Competent Authority is producing a containment policy that will set out the standards to be achieved for newly built establishments and the extent to which existing establishments must be upgraded.

Industry must learn the lessons from these incidents and implement measures to prevent similar incidents in the future - there is no excuse for complacency. It is time for operators to re-assess their secondary and tertiary containment to ensure that it is fit for purpose. Those who do not are putting people, property the environment and their own jobs at unnecessary risk. Those who act now may avoid becoming the subject of the next “lessons learned” paper.

**Figure 1.** Buncefield. Aerial picture of terminal fire & smoke plume (Photographed by Chiltern Air Support Unit)

 

**Figure 2.** Buncefield. Firefighters applying foam to tanks and bunds (Photographed by Chiltern Air Support Unit)

**Figure 3.** Buncefield. Catastrophic bund wall failure at pipe penetrations

**Figure 4.** Buncefield. Contaminated fire water flowing off-site into Cherry Tree Lane

**Figure 5.** Buncefield. Loss of integrity at a bund expansion joint

 

**Figure 6.** Buncefield. Loss of integrity at pipe penetrations

**Figure 7.** Buncefield. Damage to a lagoon liner revealing ground behind

## REFERENCES

The Buncefield Major Incident Investigation Board (BMIIB) Reports. www.buncefieldinvestigation.gov.uk

COMAH Competent Authority. Report on the findings of the Oil/Fuel Depot Safety and Environment Reviews. www.environment-agency.gov.uk

Buncefield Standards Task Group (BSTG) final report "Safety and environmental standards for fuel storage sites", July 2007. www.buncefieldinvestigation.gov.uk

Process Safety Leadership Group website. www.ukpia.com/news_press/petrochemical_process_safety_leadership_group_formed.aspx?referrertabid=1863&linktext=Petrochemical+Process+Safety+Leadership+Group+formed

COMAH Competent Authority Policy on Containment of Bulk Hazardous Liquids at COMAH Establishments, consultation draft version 1.4, 20 June 2007. www.environment-agency.gov.uk

Guidance on the Environmental Risk Assessment Aspects of COMAH Safety Reports", COMAH Competent Authority, December 1999. www.environment-agency.gov.uk