COMAH Control of Major Accident Hazards

Buncefield: Why did it happen?

The underlying causes of the explosion and fire at the Buncefield oil storage depot, Hemel Hempstead, Hertfordshire on 11 December 2005

the Competent Authority

HSE Environment Agency SEPA

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Foreword

The Major Incident Investigation Board (MIIB) set up to investigate the Buncefield explosion and fire completed its work in 2008 and published its final report.[1] At that time it was not possible to disclose all the information about the underlying causation upon which many of its recommendations were based as criminal legal proceedings were still in progress. However, now that these proceedings have concluded, this information can be brought together so that everyone in major hazard industries – not just those involved in fuel storage – can learn from this incident, understand what went wrong, and take away lessons that are relevant to them. Although five years have passed since the incident, the information and advice in this report is still highly relevant today.

The explosion and fire at the Buncefield oil storage depot in 2005 was a significant event. As part of the work of the MIIB, the Health and Safety Executive and the Environment Agency, as the Competent Authority in England and Wales for the regulation of major accident hazards, carried out a joint investigation into the cause of the incident.

The Competent Authority took action to ensure that those responsible for the incident were held to account in the criminal courts, and I emphasise our determination that, where we think it appropriate, the Competent Authority will continue to take the necessary action to ensure operators of major hazard sites manage them properly. When passing sentence on the defendants at St Albans Crown Court on 16 July 2010, the Judge, the Hon Mr Justice Calvert-Smith, commented that cost cutting *per se* was not put forward as a major feature of the prosecution case, but the failings had more to do with slackness, inefficiency and a more-or-less complacent approach to matters of safety.

I therefore ask all in the major hazard industries to look carefully at your own operations in the light of the management and technical failings that lay behind this incident, and the important developments in the meantime.

Since the incident, the Competent Authority, industry and trade unions have worked together to drive forward high standards at fuel storage sites. This has resulted in agreement on improved standards of safety and environmental protection for all UK sites storing large volumes of gasoline and to systematically upgrade sites to meet these standards, with progress monitored by the Competent Authority as part of its regulatory programmes. This work has also established a set of process safety leadership principles for top-level engagement in all businesses involved with significant risks to people and the environment – see www.hse.gov.uk/comah/buncefield/response.htm.

The Competent Authority has also improved its approach to regulating onshore major hazards in the light of ten years of operating the COMAH regime including incidents such as Buncefield. More information on the Competent Authority's remodelling programme is at www.hse.gov.uk/comah/remodelling/index.htm.

Major industrial incidents are thankfully rare and I trust this report will contribute to making them even rarer.

Gordon MacDonald
Chairman
Competent Authority Strategic Management Group

Executive summary

On the night of Saturday 10 December 2005, Tank 912 at the Hertfordshire Oil Storage Limited (HOSL) part of the Buncefield oil storage depot was filling with petrol. The tank had two forms of level control: a gauge that enabled the employees to monitor the filling operation; and an independent high-level switch (IHLS) which was meant to close down operations automatically if the tank was overfilled. The first gauge stuck and the IHLS was inoperable – there was therefore no means to alert the control room staff that the tank was filling to dangerous levels. Eventually large quantities of petrol overflowed from the top of the tank. A vapour cloud formed which ignited causing a massive explosion and a fire that lasted five days.

The gauge had stuck intermittently after the tank had been serviced in August 2005. However, neither site management nor the contractors who maintained the systems responded effectively to its obvious unreliability. The IHLS needed a padlock to retain its check lever in a working position. However, the switch supplier did not communicate this critical point to the installer and maintenance contractor or the site operator. Because of this lack of understanding, the padlock was not fitted.

Having failed to contain the petrol, there was reliance on a bund retaining wall around the tank (secondary containment) and a system of drains and catchment areas (tertiary containment) to ensure that liquids could not be released to the environment. Both forms of containment failed. Pollutants from fuel and firefighting liquids leaked from the bund, flowed off site and entered the groundwater. These containment systems were inadequately designed and maintained.

Failures of design and maintenance in both overfill protection systems and liquid containment systems were the technical causes of the initial explosion and the seepage of pollutants to the environment in its aftermath. However, underlying these immediate failings lay root causes based in broader management failings:

- Management systems in place at HOSL relating to tank filling were both deficient and not properly followed, despite the fact that the systems were independently audited.
- Pressures on staff had been increasing before the incident. The site was fed by three pipelines, two of which control room staff had little control over in terms of flow rates and timing of receipt. This meant that staff did not have sufficient information easily available to them to manage precisely the storage of incoming fuel.
- Throughput had increased at the site. This put more pressure on site management and staff and further degraded their ability to monitor the receipt and storage of fuel. The pressure on staff was made worse by a lack of engineering support from Head Office.

Cumulatively, these pressures created a culture where keeping the process operating was the primary focus and process safety did not get the attention, resources or priority that it required.

This report does not identify any new learning about major accident prevention. Rather it serves to reinforce some important process safety management principles that have been known for some time:

There should be a clear understanding of major accident risks and the safety critical equipment and systems designed to control them.
This understanding should exist within organisations from the senior management down to the shop floor, and it needs to exist between all organisations involved in supplying, installing, maintaining and operating these controls.

There should be systems and a culture in place to detect signals of failure in safety critical equipment and to respond to them quickly and effectively.
In this case, there were clear signs that the equipment was not fit for purpose but no one questioned why, or what should be done about it other than ensure a series of temporary fixes.

Time and resources for process safety should be made available.
The pressures on staff and managers should be understood and managed so that they have the capacity to apply procedures and systems essential for safe operation.

Once all the above are in place:
There should be effective auditing systems in place which test the quality of management systems and ensure that these systems are actually being used on the ground and are effective.

At the core of managing a major hazard business should be clear and positive process safety leadership with board-level involvement and competence to ensure that major hazard risks are being properly managed.

Introduction

1 Following the explosion and fire at Buncefield in December 2005 the Health and Safety Commission set up an independently chaired Major Incident Investigation Board (MIIB) led by Lord Newton of Braintree. The Board was given a wide-ranging set of objectives within its terms of reference and published a series of eight reports before its final report in 2008. Details of the Board's work and its recommendations can be found at www.buncefieldinvestigation.gov.uk.

2 Legal constraints prevented the Board from publishing certain information about the root causes of the incident while criminal proceedings were in progress. These proceedings have now concluded and this document fills that gap. It addresses the root causes behind the loss of containment of fuel on 11 December 2005. It draws out the key lessons for those managing high-hazard industries.

3 This publication is based on the work of the COMAH Competent Authority Investigation Team – over four years of investigation – and is a summary of the conclusions. It would be impracticable to repeat all the painstaking work upon which the conclusions are based, much of which formed the evidence in the criminal trial.

The Buncefield oil storage depot

4 The Buncefield oil storage and transfer depot is a tank farm in Hemel Hempstead, Hertfordshire, England, close to Junction 8 of the M1 motorway. In December 2005 there were three operating sites at the depot:

- Hertfordshire Oil Storage Ltd (HOSL), a joint venture between Total UK Ltd and Chevron Ltd and under the day-to-day management of Total UK Ltd. HOSL (the site) was divided into East and West sites;
- British Pipeline Agency Ltd (BPA), a joint venture between BP Oil and Shell Oil UK, though assets were owned by UK Oil Pipelines Ltd (UKOP). This tank farm was also in two parts, the north section and the main section which was located between HOSL East and West; and
- BP Oil UK Ltd, at the southern end of the depot.

Figure 1 Aerial view of the Buncefield depot before the incident © Chiltern Air Support

5 All three sites were 'top-tier' sites under the Control of Major Accident Hazards Regulations 1999 (COMAH). In total the depot had hazardous planning consent to store 194 000 tonnes of hydrocarbon fuels.

6 Fuel was transported to these sites through three pipelines:

- the Finaline between Lindsey Oil Refinery, Humberside and the HOSL West site;
- UKOP North line between Stanlow Oil Refinery, Merseyside and BPA; and
- UKOP South line between Coryton Oil Refinery, Essex and BPA.

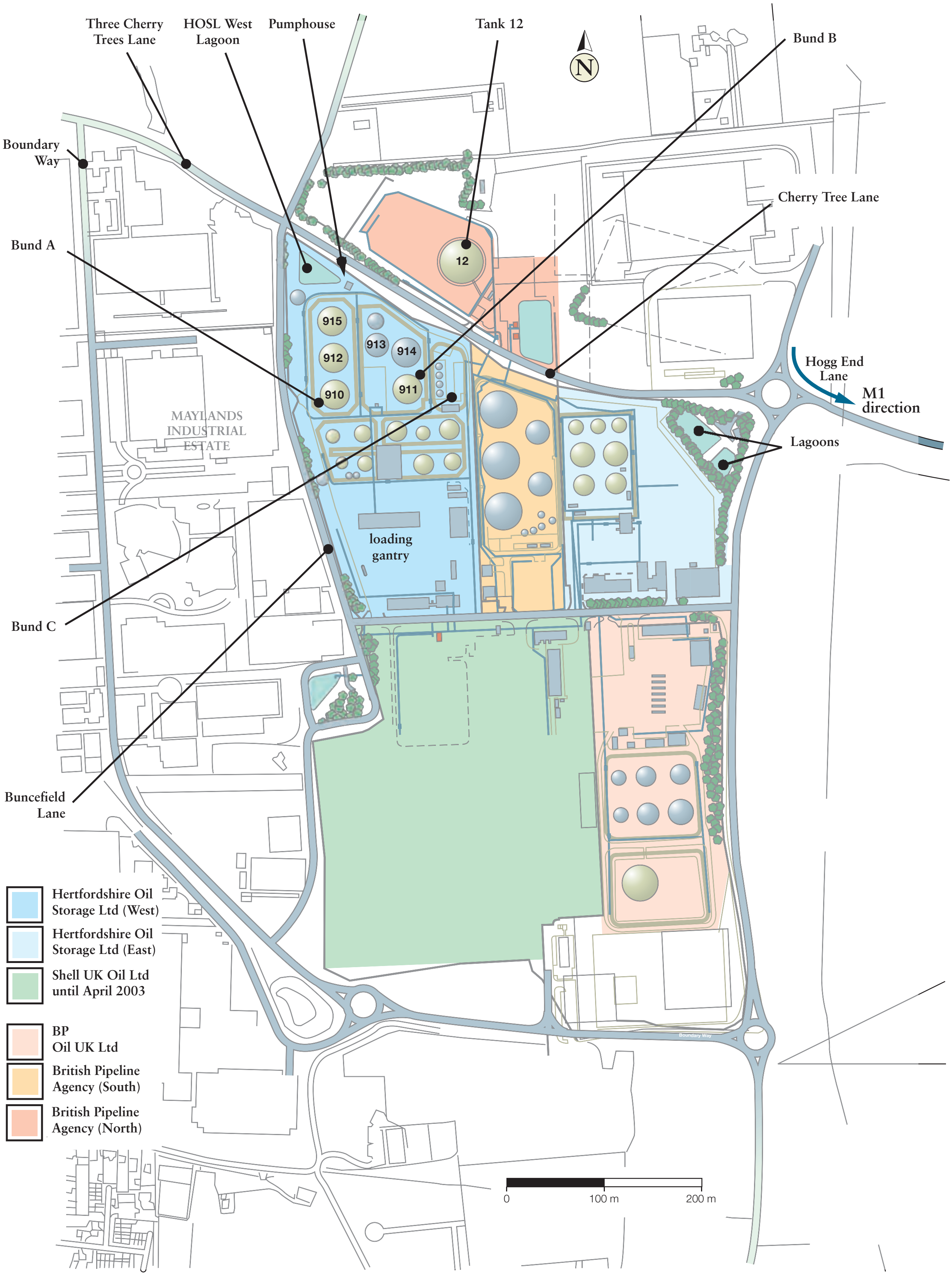

Figure 2 The layout of the Buncefield site

7 The pipelines all transported fuels in batches. At Buncefield the various grades of fuel were separated into dedicated tanks according to the fuel type. The majority of fuel was then taken from the depot by road tankers. Jet aviation fuel left the BPA site via two pipelines to the West London Walton Gatwick pipeline system then distributed to Heathrow and Gatwick airports.

8 The site was therefore of strategic importance for the distribution of fuels to London and the south-east of England and was the fifth largest fuel distribution site in the UK.

9 The Maylands Industrial Estate, one of the largest in south-east England, is immediately to the west of the Buncefield depot.

10 The depot is sited on a variable layer of clay with flints, 2 to 10 metres thick, over the Upper Chalk stratum. The Upper Chalk is classified as a major aquifer that provides drinking water as well as other uses including private abstractors, agriculture and industry.

The incident and its aftermath

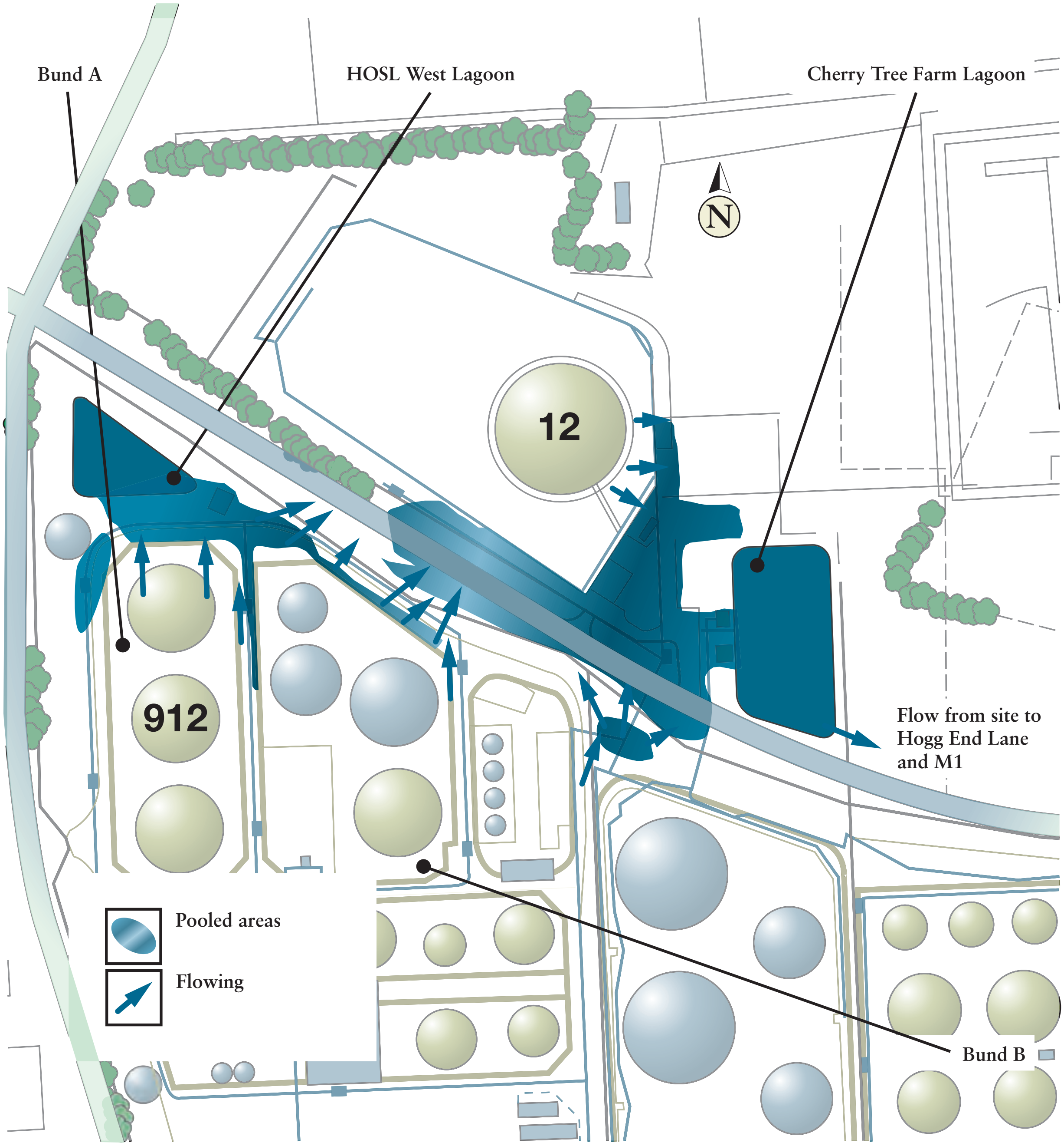

Figure 3 Layout of the Buncefield site showing flow of liquids

11 A parcel of unleaded petrol was being delivered through the UKOP South line into HOSL's Tank 912 from 1850 hrs on Saturday 10 December 2005. The tank, which had a capacity of 6 million litres, was fitted with an automatic tank gauging system (ATG) which measured the rising level of fuel and displayed this on a screen in the control room. At 0305 hrs on Sunday 11 December the ATG display 'flatlined', that is, it stopped registering the rising level of fuel in the tank although the tank continued to fill. Consequently the three ATG alarms, the 'user level', the 'high level' and the 'high-high level', could not operate as the tank reading was always below these alarm levels. Due to the practice of working to alarms in the control room, the control room supervisor was not alerted to the fact that the tank was at risk of overfilling. The level of petrol in the tank continued to rise unchecked.

12 The tank was also fitted with an independent high-level switch (IHLS) set at a higher level than the ATG alarms. This was intended to stop the filling process by automatically closing valves on any pipelines importing product, as well as sounding an audible alarm should the petrol in the tank reach an unintended high level. The IHLS also failed to register the rising level of petrol, so the 'final alarm' did not sound and the automatic shutdown was not activated. By 0537 hrs on 11 December, the level within the tank exceeded its ultimate capacity and petrol started to spill out of vents in the tank roof.

13 CCTV evidence showed that soon after that a white vapour was seen to emanate from the bund around the tank. In the windless conditions this vapour cloud, which was likely to have been a mixture of hydrocarbons and ice crystals, gradually spread to a diameter of about 360 metres, including areas off the HOSL site. This included a car park on the Maylands Estate, and onto the BPA north site where Tank 12, containing aviation kerosene, was situated.

14 The vapour cloud was noticed by members of the public off site and by tanker drivers on site waiting to fill their vehicles. They alerted employees on site. The fire alarm button was pressed at 0601 hrs, which sounded the alarm and started the firewater pump. A 'vapour cloud explosion' occurred almost immediately, probably ignited by a spark caused by the firewater pump starting. By the time the explosion occurred, over 250 000 litres of petrol had escaped from the tank.

Figure 4 Firefighters tackle a blazing tank at Buncefield © Hertfordshire County Council

15 The severity of the explosion was far greater than could reasonably have been anticipated based on knowledge at the time and the conditions at the site. The devastation was enormous. Fortunately there were no fatalities but over 40 people were injured. The ensuing fire, the largest seen in peacetime UK, engulfed over 20 fuel tanks on the HOSL and adjacent sites and burnt for several days. Fire crews attended from many parts of the country. Fuel and firefighting chemicals flowed from leaking bunds down drains and 'soakaways', both on and off site. The environmental, social and economic toll was considerable. The human toll should not be underestimated; while no one lost their life some have yet to fully recover from the effect that the explosion had on their lives. The human effects may have been even greater had the event not occurred early on a Sunday morning when the adjacent industrial area was relatively quiet.

Figure 5 Part of the Buncefield depot after the incident © Chiltern Air Support

Figure 6 Buncefield after the incident: Tank 912 is in the centre foreground and Tank 12 is in the top left of the picture © Chiltern Air Support

16 The fire lasted five days and large quantities of water and firefighting foam were used to bring the blaze under control. Fuel, water and foam spilled from leaking bunds formed a large pool of liquid to the east of BPA Tank 12. Liquids subsequently flowed down Cherry Tree Lane, past the roundabout into Hogg End Lane and as far the M1 motorway bridge, several hundred metres away.

17 The adjacent area contained a number of drains and soakaways that the site operators had not identified and liquids were able to penetrate into the soil beneath them. The pollutants in this liquid run off consisted of PFOS (perfluorooctane sulphonate) from the foam, and hydrocarbons such as benzene and xylene. These pollutants have entered the chalk stratum below the site which is an aquifer from which potable water is extracted. The contamination close to the site did not affect drinking water supplies but the long-term possibility of pollution remains. The Environment Agency has a monitoring programme to check on the level of pollutants in the aquifer.

Root causes of the loss of containment

18 The immediate cause of this major incident was the failure of both the ATG and the IHLS to operate as the fuel level in Tank 912 increased. This was a loss of 'primary' containment.

19 During and following the fire there were subsequent failures of 'secondary' and 'tertiary' containment. So what lay behind the immediate cause and subsequent failures of containment? In other words, what in terms of the overall management of operations at this high-hazard site led to these failures? What, in the processes and systems, failed to deliver the necessary high level of control of site operations? Understanding these root causes will allow those managing high-hazard industries to learn from the experience of Buncefield.

The independent high-level switch

20 Tank 912 was fitted with a new independent high-level switch on 1 July 2004. This had been designed, manufactured and supplied by TAV Engineering Ltd. TAV had designed the switch so that some of its functionality could be routinely tested. Unfortunately, the way the switch was designed, installed and maintained gave a false sense of security. Because those who installed and operated the switch did not fully understand the way it worked, or the crucial role played by a padlock, the switch was left effectively inoperable after the test. (A fuller description is in Appendix 1.)

Designers of equipment for use in high-hazard operations should have systems in place to ensure that the equipment is safe so far as is reasonably practicable.

21 The design fault could have been eradicated at an early stage if the design changes had been subjected to a rigorous review process. In any event, clear guidance, including instructions about the safety criticality of the padlock, should have been passed on to installers and users.

22 TAV was aware that its switches were used in high-hazard installations and therefore were likely to be safety critical.

Designers and suppliers should have adequate knowledge of the environments where their equipment will be used.

23 The impact of these defects in switch design, and the failure to inform users and suppliers of the change in criticality of the padlock, could have been reduced by those further down the supply chain. Motherwell Control Systems 2003 Ltd ordered the IHLS from TAV but the ordering process by both parties fell short of what would be expected for safety critical equipment intended for such a high-hazard environment. The information TAV provided did not give sufficient clarity about the key aspects of the IHLS design and use, and TAV should have enquired as to the intended purpose of the switch and formed a view as to its suitability – in this case for a high-level only application. Motherwell staff were highly experienced in this field although the company itself had only recently come into existence as the result of a management buy-out. However, their systems for checking and understanding equipment again fell short of the mark.

24 It appears that nobody within Motherwell knew the safety critical significance of the padlock. The IHLS on Tank 912 was installed without the padlock because it seems that Motherwell staff thought it was for security 'anti-tamper' purposes only. After the periodic tests, the lever was left unsecured either in the inoperable position or so that it could fall into that position. While they ought to have been able to rely on TAV to tell them, Motherwell staff equally should have known better. The elements of Motherwell's failure were:

- The process for ascertaining and then specifying the requirements of switches they supplied and/or installed was not adequate.
- They did not obtain the necessary data from the manufacturer and it follows that they did not provide such data to their customers.
- They did not understand the vulnerabilities of the switch or the function of the padlock.
- There was a reliance on TAV, which was not justified given the lack of information provided and the critical role that Motherwell had in installing safety critical equipment.

25 In addition to the failures of the manufacturers and installers of the IHLS, the site operator did not exercise sufficient oversight of the ordering, installation and testing procedure. While the switch was periodically tested, none of the staff at the HOSL site was aware of the need for the padlock to be replaced so that the test lever was held in the correct position. The site operator should have had greater oversight of safety critical operations and equipment so that they understood fully how it worked, particularly given the expertise available within large oil companies.

The automatic tank gauging system

26 Failure of the ATG system was the other immediate cause of the incident. The servo-gauge had stuck (causing the level gauge to 'flatline') – and not for the first time. In fact it had stuck 14 times between 31 August 2005, when the tank was returned to service after maintenance, and 11 December 2005. Sometimes supervisors rectified the symptoms of sticking by raising the gauge to its highest position then letting it settle again, a practice known as 'stowing'. On other occasions Motherwell was called in to rectify the matter, although the definitive cause of the sticking was never properly identified. Sometimes the sticking was logged as a fault by supervisors and other times it was not.

27 The failure to have an effective fault logging process and the lack of a maintenance regime that could reliably respond to those faults were two of the most important 'root cause' managerial and organisational failures underlying the incident. Further, Motherwell staff never saw that the unreliable gauge should be investigated. They did not analyse why they had been called out so frequently nor questioned the reliability of the system.

Other shortcomings

28 The system also had other shortcomings that could fairly easily have been remedied:

Monitoring screen

29 There was only one visual display screen for the data provided by the ATG system on a number of tanks which meant that the status of only one tank could be fully viewed at a time. On the night of the incident the display relating to Tank 912 was at or near the back of a stack of four other tank display 'windows'. Only one computer was provided, with no back up, to run the entire ATG system. The supervisors relied heavily on the ATG system to control tank filling so having no back up for this critical control process was inadvisable.

Redundant emergency shutdown

30 The tank mimics on the screen showed a red 'stop' emergency shutdown button. Use of this was meant to close all tank side valves. Unbeknown to a number of the supervisors this was not working and had never been fitted into the system. Had it worked it may have provided a useful emergency procedure although it may have taken several minutes for the valves to close. This issue is indicative of poor management control where supervisors did not appreciate the redundancy of the 'stop' button and Motherwell staff never tested it. This meant that there was no proactive facility on the site to close down two (UKOP) of the three incoming pipelines. The Finaline had an emergency shutdown button accessible in the site control room.

System security

31 While there is no indication that it had any bearing on the incident, the security arrangements on the ATG system were lacking. It had its own built-in security system but this had been set so that all control room staff could modify any parameter including being able to change the alarm settings.

Alarm function

32 Later versions of the ATG system had the ability to be set to alarm in the event of inconsistencies between tank level measurements and filling data, which would have provided a way of alerting control room staff to an 'unexpected' static reading. Had such a modification been made then supervisors may have been made aware of the sticking gauge before an overfill position was reached. A more stringent monitoring scheme could have identified the shortcomings and allowed the site operator to upgrade the ATG system.

Wider underlying causes

33 The sticking gauge and inoperative IHLS were the technical causes of the overfilling of Tank 912, and were a consequence of the underlying management failures set out below.

Control of incoming fuel

34 It is essential to understand the significant difference for the supervisors in the way they controlled receipt of fuel 'batches' from the Finaline and the two UKOP lines. The Finaline was controlled by the supervisors, while for historical reasons the UKOP lines were controlled from elsewhere.

35 There was also a stark contrast in the information available to them about the three pipelines. For the two UKOP lines the HOSL supervisors did not have access to the SCADA monitoring systems to tell them, independently of the ATG system:

- whether the UKOP lines were on or off line; and
- if online, the flow rate.

36 In theory the UKOP flow rates could be determined from the speed at which the tank was filling. This was not an easy task because tanks could be filling from the pipeline while simultaneously feeding the tanker bays. More than one tank could be filling at any one time and flow rates were likely to vary according to external factors. Advance planning of deliveries from the UKOP lines would have been difficult and sometimes well nigh impossible. Significantly, no suitable advance planning system was in place. Changes in flow rates were significant and sometimes the HOSL supervisors were not informed. For example, shortly before the explosion, the flow rate in the UKOP South line changed from 550 m^3/hr to 900 m^3/hr without the knowledge of the supervisors.

37 This lack of information undermined the ability of supervisors to plan and control the management of fuel. This was exacerbated by an understanding among staff that the UKOP lines had to be given priority over the Finaline for fear of the site operator incurring a financial penalty if the UKOP lines were slowed or stopped.

38 A further example of lack of control over the UKOP lines was that the only way an emergency shutdown could be achieved was by:

- a telephone call to another terminal;
- operation of an IHLS; or
- activation of a manual call point on the adjacent BPA site.

39 Unsurprisingly this lack of control over the UKOP lines was unpopular with the supervisors. It contributed to the pressure under which some of them felt they had to operate.

40 Importantly, Control Room operations should have been subject to a risk assessment but none had been carried out.

Increase in throughput

41 Since the early days of the terminal's operation in the late 1960s, there had been a four-fold increase in throughput of product. A significant proportion of this increase had occurred when the adjacent Shell terminal closed in 2002 and its throughput was absorbed into the HOSL terminal. This led to an inevitable increase

in the number of tanker drivers and contractors on site, which clearly affected the workload of supervisors. The result was considerable pressure on ullage space with batches diverted between tanks to prevent overfilling. The necessary ullage would become available by virtue of tanks being emptied through tankers at the loading bays.

42 There is evidence to suggest that on the night of the incident the supervisors were confused as to which pipeline was filling which tank. Large batches of unleaded fuel were being received at site from both the Finaline and the UKOP South line. This confusion arose because of deficiencies in the shift handover procedures and the overlapping screens on the ATG system. Given the increased pressure that staff were under, and lack of sufficient data in the control room, such confusion is easily understood.

43 To manage the pressures, staff were working a considerable amount of overtime which was costly. To overcome this management tried to recruit a further supervisor. However, when a new member of staff was recruited it was immediately counterbalanced by the resignation of another.

Tank filling procedures

44 The supervisors' main duty was operating and monitoring the control systems relating to movement and storage of fuel, including control of the Finaline. A key role was the filling and emptying of tanks at HOSL. The ATG system was capable of providing supervisors with readings of a number of parameters. Supervisors viewed the ATG data on one screen and could call up screen images, one on top of another. As noted earlier, it was not possible to see the status of more than one tank at any one time. Often, three or four 'windows' would be 'stacked' on the computer screen, one behind another, so that the supervisor had to make a conscious decision to bring a hidden screen in to view. For level measurement the system was designed with a series of audible and visual alarms to alert the supervisor to the need to take action at various product levels within the tank.

45 Essentially there were three 'high level' alarms. These were:

- the 'user high' which could be set by the supervisor to indicate that intervention was required;
- the 'high' level – set at a level in the tank below its maximum working level; and
- the 'high-high' level – set below the level at which the IHLS was intended to operate.

46 Each of the eight supervisors used these alarm levels in their own way. For example, sometimes the level was allowed to pass the 'high' level alarm. Less frequently, pressure on storage space meant that the level was allowed to rise to the 'high-high' alarm and on occasions beyond even that. The supervisors relied on the alarms to control the filling process.

47 Such written work procedures as there were relating to the filling process were short on detail. They gave no guidance as to how to choose the tanks which had to be filled or in what circumstances, if any, it was appropriate to deliberately fill a tank above the high or the high-high level. If such a procedure was deemed by management to be appropriate, there was no guidance to support this, ie there was no description of:

- extra safeguards;
- reporting such events; and
- an effective investigation of the cause of the event.

48 In summary, there was no tank filling system worth its name. Considering that this was the single most important process control system to prevent loss of containment of fuel, this was a serious management failure in the control of a major accident hazard.

49 A robust safe system of work should have been in place to ensure that all supervisors controlled tank filling in a consistent, safe way, and that when situations arose which required them to work outside the normal operating envelope, this was recorded and reviewed by management.

When situations arise requiring staff to work outside the normal operating envelope they should be recorded and reviewed by management.

Pressure of work

50 The tank filling system, ill defined as it was, was further undermined by the unreliability of the whole ATG system as exemplified by the gauges sticking. Supervisors also had to deal with their inability to predict the working parameters of the UKOP lines and the resulting unpredictable nature of fuel deliveries through those lines. These factors were in addition to the pressure on the storage capacity caused by increased throughput at the terminal.

51 All this added up to a system that put supervisors under considerable pressure. Supervisors developed their own systems to overcome this. For example, they introduced a small alarm clock into the control room and used this to track product interfaces on the Finaline and on occasions as an additional reminder that tanks were getting close to their full capacity. The lack of confidence in the system was also demonstrated when one supervisor asked for a back-up IHLS, as the ATG system was becoming unreliable.

52 This pressure was not helped by working patterns. Supervisors worked 12-hour shifts and had other duties as well as the constant monitoring of the filling and emptying of tanks. Supervisors were 'blocked' to work five shifts in a row, which with overtime working sometimes led to 84 hours of working in a seven-day period. No fixed breaks were scheduled; they took a break when operating conditions allowed. Supervisors worked large amounts of overtime and resisted the employment of an additional supervisor as this would result in a loss of income.

53 Management failed to recognise these unacceptable working pressures, although when the Operations Manager offered his resignation shortly before the incident because of the pressurised environment this should have confirmed that all was not well.

Management has a duty to monitor working pressures on staff and take action to keep workloads to acceptable levels so far as reasonably practicable.

Inadequate fault logging

54 The investigation revealed that fault logging at HOSL, in relation to key equipment and working practices, was inadequate. The shift system of working led to short-term apparent fixing of problems with no proper overview of what was going wrong and why.

55 The handover time (overlap) for supervisors between shifts was short. It was an important time when outgoing supervisors could pass on information about events during their shift. They tried to allow 15 minutes for handover but were conscious that they were not being paid for their time. The handover documentation was designed to capture information for the Finaline only and information on the UKOP lines, if captured at all, was on an ad-hoc basis. It also only captured information at the end of the shift rather than recorded incidents that happened during the shift.

56 The Operations Co-ordinator had devised an electronic defect log but the supervisors did not use it properly. While the ATG gauge on Tank 912 had stuck 14 times during the three months before the incident, this was not recorded on the defects log and the Operations Manager was unaware of the frequency of failure. It appears that the defect logging system was not consistently used, especially where the symptoms of a defect were apparently remedied quickly, by, for example, stowing the gauge or an early visit from Motherwell. Staff on site were unaware of the extent of the unreliability of safety critical equipment, and there was no system in place for senior management to monitor key safety parameters.

57 There was a similar situation with the IHLS. Faulty procedures and practices were not properly dealt with. The failings of the ATG system meant that there was greater dependence on the IHLS; as the IHLS was frequently left in an inoperable state, there was greater reliance on the ATG. The fact that both systems could not be relied upon meant that the overall control of the tank filling process was seriously weakened. Management failed to scrutinise the combined unreliability of the ATG system and inoperable IHLS.

58 For example, by the first week of April 2004 it was known that the IHLS on Tank 912 was not working but the tank remained in use and a new switch was not fitted until 1 July 2004. Similarly, it was found that before this Tank 911, a very busy unleaded petrol tank, was operating without an IHLS for at least nine months. A thorough defect logging system, properly scrutinised by senior management, would have revealed the serious vulnerability of the overall system.

Management should have in place systems to monitor the reliability of safety critical equipment.

Motherwell Control Systems

59 Motherwell Control Systems was used to supply and install the IHLS and to maintain the ATG system. This was a vital contractual relationship. Its importance was underlined in an independent audit of the site. The audit report in 2004 stated that:

> 'Contract co-ordinators should be competent to perform the function, and their competence requirements should be linked to the contract risk level. At the lower level, terminal staff should be given training to become competent, whereas it may be necessary to hire in specialists for high risk contracts.'

60 The contract with Motherwell was clearly a safety critical arrangement and the competence and training of Motherwell staff working with critical equipment should have been evaluated. There appears to have been little if anything done in response to this comment from the auditors. Some information about Motherwell was obtained before 2000 but this was before the formation of a new company 'Motherwell Control Services 2003 Ltd'. While Total had a 'contractor site performance evaluation', this was about personal protection on site and not an assessment of technical ability.

61 Where contractors are engaged to carry out work upon which the safety of many and much depends, something more rigorous than the evident casual relationship with Motherwell was called for:

- There should have been a formal contract in place clarifying the expectations inherent in safety critical work.
- There should have been an effective system of reporting and recording all significant faults and their resolution. This system should have been understood and implemented by both contractual partners.
- Reliable and up-to-date specifications of what was in place and what was required should have been provided.
- Critically, in respect of the replacement of the IHLS switches in 2004, there should have been a formal 'management of change' process. This typically would have included an engineering assessment of the benefits and disadvantages of any such change, and a consideration of what changes in procedures (eg in testing) would be necessary as a result.

For high-hazard risks dutyholders should have formal arrangements that specify the roles of all parties involved to ensure so far as is reasonably practicable that the highest standards are provided for safety critical equipment.

Loss of secondary containment

62 The bunding at Buncefield had many flaws, which caused large volumes of fuel, foam and firefighting water to leak out of the bunds. Bunds were not impermeable and not fire resistant. The bunding was unable to handle the large volumes of firewater involved in the incident.

63 Generally, the concrete performed well in resisting the burning fuels but the bunds failed badly at the joints and walls where pipes penetrated them.

Bund joints

Any concrete structure for retention of liquids should be designed to minimise the risk of cracks forming. If cracks do form they should be adequately repaired.

64 Guidance on limiting cracking is given in BS 8110[2] and BS 8007[3] and often involves including 'movement joints' between concrete slabs to allow for expansion and contraction. Joint design is critical to ensure liquid retention – 'waterstops' in bund expansion joints are key to their integrity and performance in containing liquids following a major accident. The joints should also be fire resistant, which can be achieved by a metal waterstop and fire-resistant sealants. The Buncefield incident also demonstrated that placing metal plates over movement joints was an effective means of improving the fire resistance of the joint. Part 4 of the Process Safety Leadership Group's (PSLG's) final report[4] provides further detail on these issues.

65 One of the bunds at Buncefield contained metal waterstops within joints. Even though this bund was exposed to a bund pool fire and tank fires, the joints performed well and did not leak significantly. Other bunds had plastic waterstops with metal plates over the inside face of the joint. These joints also maintained their integrity as the plastic waterstop and other joint material was protected from thermal impact by the metal cover plate. One bund, which was not exposed to fire but used to store liquids during the response, leaked slightly at joints where there were no waterstops, though it had been fitted with metal cover plates.

66 Within the HOSL site, three bunds – bunds A, B and C – performed particularly badly. The joints (floor and wall joints) did not contain waterstops. During the fire the sealant and other joint materials (which were not fire resistant) were badly damaged. Many of the joints leaked allowing fuel, foam and firewater to flow onto the site roadways.

67 HOSL could and should have identified, before the incident, that the bunds were not fit for purpose. As a top-tier COMAH operator HOSL provided a safety report in which compliance with industry codes was asserted. If HOSL had reviewed the detailed design of their bunds during the preparation of this report they would have identified that the bund joints were not impermeable and fire resistant as required by those codes. Moreover, on occasions, joint leaks were seen by staff on site. Leakages noted by staff in bund A had not been repaired by the time of the incident and HOSL had not investigated the root cause of these leaks.

68 The BPA Tank 12 bund also leaked extensively at joints. This bund was built in 2002, and the original specifications required a liquid-retaining structure, citing BS 8007 and the civil engineering specification for the water industry.[5] However, BPA failed to manage the project to ensure that changes during the design and build were properly assessed. Waterstops were not fitted into the bund joints. As a result (and as with HOSL bunds A–C) fire damage to the joints allowed fuel, foam and firewater to leak out of the bund. This bund suffered further loss of integrity due to positioning of movement joints at shallow (obtuse) wall corners.

Tie bar holes

69 Another failure mode of the BPA bund was introduced at the construction phase. The shuttering (or formwork) used to hold the concrete in place before it set was held in place using tie bars (or tie bolts). Good practice requires either use of formwork techniques avoiding tie bolts or use of 'tie bar waterstops'. The BPA bund was constructed with tie bars penetrating through the bund and, although they were plugged and grouted, they were unable to resist the impact of the fire. Holes opened up, which were further pathways for leakage of fuel, foam and firewater from the bund.

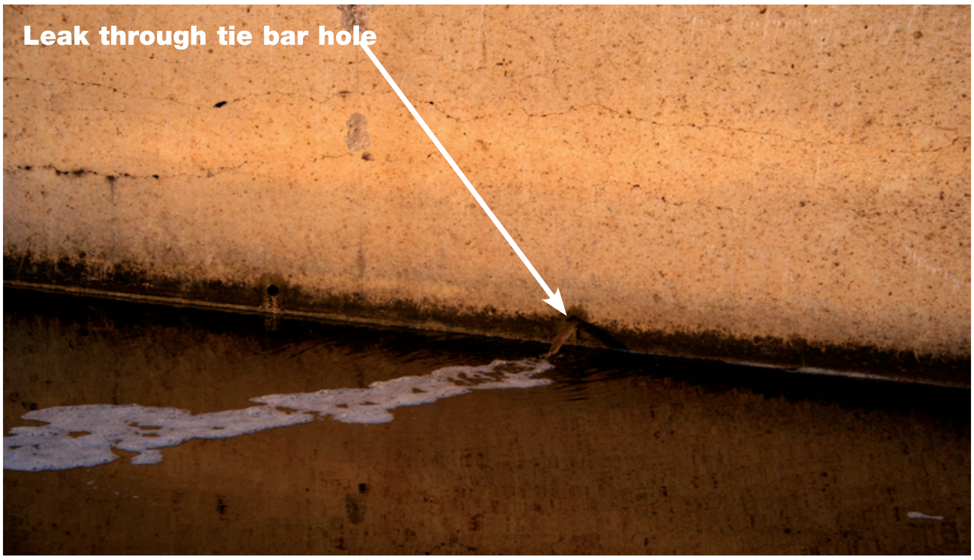

Figure 7 Tank 12 after the incident showing liquid leaking through tie bar hole

Pipe penetrations

70 Good practice (*Storage of flammable liquids in tanks* HSG176[6]) states:

> 'The integrity of the bund wall may be put at risk if pipework and other equipment are allowed to penetrate it. If it is necessary to pass pipes through the bund wall, for example to the pump, then the effect on the structural strength should be assessed. Additional measures may be needed to ensure that the bund wall remains liquid tight.'

71 Many of the HOSL bunds had pipes penetrating through walls and floors, and failures at these points meant the bunds could no longer retain liquids. Broadly, there were three ways loss of integrity occurred:

- catastrophic failure of the walls at pipe penetrations, likely due to thermal expansion of the pipework;

Figure 8 Catastrophic bund wall failure at pipe penetrations

- some of the product pipes leading from the tanks ruptured and leaked so that there was an escape of fuel via damaged pipes through the walls and out of pipes in unbunded areas; and
- loss of seal between pipes and walls.

Figure 9 Loss of sealant between penetrating pipe and bund wall

72 Buncefield also highlighted serious concerns about bunding arrangements for managing firewater. If bunds fill to the point of overflowing then burning fuel (which floats on water) can escape over the top of a bund. At Buncefield removal of water from the bunds was difficult because drainage valves were inaccessible and there was no pumping from interceptors due to the site-wide loss of power. In the event only one bund overtopped because the failures set out above meant other bunds leaked rather than filled. This leads to consideration of tertiary containment.

Tertiary containment

73 At Buncefield there was virtually no tertiary containment in place. Containment systems outside the bunding amounted only to the site's drainage systems, designed for rainwater and minor spills and losses of product, which would flow to interceptors and the site's effluent treatment plant. The drainage was not designed for any large-scale releases from bunds, such as those that occurred.

74 Specific flaws included:

- There was no kerbing or boundary wall/mound to keep liquids on site and direct them into drainage systems. Once released, liquids could flow anywhere.

Figure 10 Fuel and firefighting liquids flowed off site

- The capacity of the drains and the lagoon was too small.
- Some of the drains were 'perforated' so that a 'back up' of liquids would cause their release through underground perforations.
- The liner of the firewater lagoon was susceptible to fire damage and to damage from debris from the explosion.

Figure 11 The firewater lagoon on the HOSL site after the incident

- The HOSL West lagoon was intended as a firewater supply, but was rendered useless as it received fuel draining from the site. It flooded the fire system pump house when it overflowed.
- There was a dependence on pumping liquids, which as a process is vulnerable to, for example:
  – inadequate pumping capacity;
  – failure of pumps on loss of power; and
  – inability to use pumps following release of flammable vapour.
- Some areas of unmade ground were not protected from liquids and one such area of the site included a soakaway.
- The effluent treatment plant included soakaways that were not identified in the safety reports or emergency plans.

75 Collectively these flaws allowed large volumes of fuel, foam and firewater to leave the site.

Where appropriate tertiary containment should be provided to ensure that in the event of a spillage of hazardous liquids, such as fuel or fire run-off water, these are contained and pollution is prevented.

Emergency arrangements

76 One of the fundamental objectives of the COMAH Regulations is to ensure adequate emergency arrangements are in place before an incident occurs.

The assessment of risks posed by a site should provide the necessary foresight to develop response plans. For environmental protection, risk assessments should identify, for credible accident scenarios, all on- and off-site pathways to environmental receptors so that measures to reduce environmental impact can be planned, implemented, maintained and exercised.

77 Many lessons have been highlighted following Buncefield including:

- Risk assessments should adequately reflect potential worst-case scenarios involving multiple tank/bund fire and large volumes of firewater run-off. To inform incident response strategy, operators should assess the consequences of various firefighting decisions (eg controlled burn versus extinguishment).
- Up-to-date drainage plans for areas on and off site should be readily available to emergency responders before and during an incident (to include topographical detail for surface flows and subsurface drainage features). The HOSL West site had drainage and a soakaway that were not featured on current plans but were shown on older company plans. Neither HOSL nor BPA had identified the presence of two soakaways in a dip in Cherry Tree Lane, located between HOSL West and the BPA Tank 12 site. These were discovered during the investigation and were found to contain contaminated liquids draining into the ground and the underlying aquifer. Had they been identified before the incident then measures could have been taken to remove or protect these pathways.
- Contracts for spill response need to be in place before incidents occur. As highlighted in guidance on emergency planning for COMAH (*Emergency planning for major accidents* HSG191[7]) the administrative structures and arrangements need to be in place to facilitate rapid clean up in case it is needed after an incident. For oil spills, this includes use of oil spill responders accredited under the UK Spill scheme. Those responders should be involved in planning and exercising arrangements for spill response. The UK Spill Contractors Accreditation Scheme has replaced the British Oil Spill Control Agency accreditation (see www.spillonline.org/).
- Procedures (eg risk assessments and method statements) should be prepared, agreed and tested before an incident. This will enable the appropriate emergency response actions to be resourced and available. Measures to protect the environment should not conflict with measures to protect human health. Lack of advance planning may delay mitigation of environmental impact (see HSG191).

78 More guidance on these issues can be found in the PSLG final report.

Safety management systems, managerial oversight and leadership

79 Safety management systems at the HOSL site were embedded in the safety report that is required to be produced for a top-tier COMAH site. The safety report was therefore a vehicle in which HOSL could, and indeed did, set out their principles for managing the major hazard aspects of their operations. However, what was set out in the document and the safety management systems did not reflect what actually went on at the site. For example, a critical parts list was required for maintenance and was stated to have been critically reviewed as a result of risk assessment. In reality the list was put together without any fundamental rationale. The safety report required a management of change exercise for replacing critical equipment but no such procedure was considered when the IHLS on Tank 912 was replaced in 2004.

80 The loss of secondary and tertiary containment at both the HOSL and BPA sites can also be traced back to failings in the respective safety management systems. The bunding failures found at Buncefield resulted from several underlying root causes within the safety management system.

Bunds should be treated as safety critical equipment. They should be designed, built, operated, inspected and maintained to ensure that they remain fit for their containment purpose.

81 At Buncefield, the operators' management systems were inadequate in several respects:

- Risk assessments did not consider the implications of more than one tank being on fire. They did not assess release of large volumes of fuel and firewater as might occur following explosion and/or escalation – scenarios known to the site operator before the incident. The risk assessments also failed to consider that bunds might fail structurally (eg due to impact of fire) as well as their capacity being exceeded.
- Systems for control of contractors (including those designing and constructing bunds) did not ensure bunding work was in accordance with good practice.
- Management of change procedures were not adequately applied to bund projects. Changes during design and construction were not reviewed in terms of impact on the ability of the bund to retain liquids during an incident.
- Bunds were not subject to an adequate inspection and maintenance regime.
- There was no periodic review of the bunds' characteristics compared to up-to-date standards and guidance. (This is one purpose of safety reports.)
- Bund failures were not treated as 'near misses'. This would have triggered an investigation of the root cause of those failures and enabled corrective actions to be implemented.

82 Collectively, these failings represent many missed opportunities for the operators to ensure better bunding arrangements.

Management of the HOSL site

83 Day-to-day operations of the HOSL site were undertaken and managed by Total through Total employees. Therefore, it was incumbent upon Total management to provide the day-to-day support for its staff. The overall responsibility for managerial oversight of the HOSL site remained with HOSL the company as the operator under the COMAH Regulations. Although HOSL could choose how it discharged its COMAH function, it could not delegate its obligations as operator.

84 Total Head Office in Watford had considerable influence over systems of work of the HOSL site and was supposed to provide the necessary engineering support and other expertise. In reality that support was lacking. Both the Operations Manager and the Terminal Co-ordinator had too much to do. The latter was given insufficient direction on how to prioritise and had insufficient expertise and resources to cope with the duties placed upon him. In particular, he was given little help in implementing the safety management system.

85 The Loss Control Manual was handed down to the site by Watford Head Office. Had the systems within the Loss Control Manual actually been implemented, the Buncefield incident may well have not occurred. A more thorough scrutiny of actual practices would have uncovered this discrepancy and indeed such an approach is vital for the rigorous management of major hazards.

86 For example, there was a requirement within the Manual to provide a list of safety critical parts. No real guidance and resources were provided to achieve this objective. The resulting list was inaccurate and could not be used as an effective tool for maintaining vital safety-related equipment.

87 The lack of a critical parts list was an example of the poor focus on major hazard systems and plant. At the HOSL site there was no adequate framework to set process safety indicators. Had such a framework been in place, the measurement of a number of relatively simple indicators would have alerted management to the underlying problems that led to the incident.

88 Further, the safety management system focused too closely on personal safety and lacked any real depth about the control of major hazards, particularly in relation to primary containment.

Good process safety management does not happen by chance and requires constant active engagement. Safety management systems at COMAH sites should specifically focus on major hazard risks and ensure that appropriate process safety indicators are used and maintained.

89 For the purposes of the COMAH Regulations, Hertfordshire Oil Storage Ltd was the operator of the HOSL sites. HOSL was responsible for the preparation and submission of the COMAH safety report. HOSL had a board of directors but no employees, a challenging set up for a company whose responsibilities included the control of a major hazard site.

90 The safety report was prepared by a contractor, but never scrutinised by the HOSL Board. In fact the HOSL Board met only twice a year and were kept informed of health, safety and environmental issues by the Terminal Manager. Such a hands-off approach was clearly insufficient oversight to achieve the stringent managerial framework required for the control of a major hazard site. As with Total, it resulted in an unjustified confidence in the safety and environmental performance of the site. Among other things, it led to the delay in employing a ninth supervisor

and the failure to provide finance for tertiary bunding. Had the Board taken a more detailed interest in operational safety, they may well have realised the safety implications of sanctioning an additional supervisor. Similarly, a greater interest in the safety report would have allowed them to see that some aspects of the report were 'aspirational', rather than a true reflection of conditions on site.

91 In summary:

- the Board of HOSL did not grasp its COMAH responsibilities; and
- the HOSL joint venture did not effectively manage major hazards. It appeared more of a convenience for the financial management of the venture.

Clear and positive process safety leadership is at the core of a major hazard business and is vital to ensure that risks are effectively managed. It requires board-level involvement and competence. Board-level visibility and promotion of process safety leadership is also essential to set a positive safety culture throughout an organisation.

Conclusion

92 A detailed investigation into a major incident provides a unique opportunity for the regulator to assess the full managerial processes involved at a particular site. It is therefore important, when such opportunities arise, that the lessons are learnt. In the Buncefield incident, the story of the sticking gauges and the inoperable high-level switch tells us about the immediate (technical) causes of the incident. However, the underlying managerial failures by others were equally important and have wider implications across all major hazard industries. These managerial failures encompass the cause of an incident and the mitigation processes. A study of these underlying causes and management failings reinforces the recommendations made by the MIIB but it is worth adding emphasis to certain issues.

93 In relation to the Buncefield incident:

- the process safety controls on safety critical operations were not maintained to the highest standard;
- senior managers did not apply effective control;
- effective auditing systems were not in place. Auditing and monitoring arrangements focused on whether a system was in place; the audits did not test the quality of the systems and, most importantly, did not check whether they were being used or were effective.

94 Secondly, the Buncefield incident has shown that the high standards expected of operators of safety critical equipment apply equally to all those involved in the supply of that equipment. At Buncefield the designers, manufacturers, installers and those involved in maintenance did not have an adequate knowledge of the environment in which the equipment was to be used. They were unable to make the right decisions about the standards they needed to apply to their work. To summarise, the design, installation and maintenance of safety critical equipment was just as important as the operational process controls.

95 Given that the relationship between the operator and its contractors in this context is so important, it follows that the operator should not have taken the work of their contractors for granted. HOSL did not act as an 'intelligent customer' and could not be assured of the service they were obtaining from their contractors. They did not provide the necessary expertise or adequate resources to achieve this. A safety report is not a chore to satisfy the regulator. In preparing its safety report HOSL missed an ideal opportunity to look critically at its own systems and managerial arrangements intended to 'prevent major accidents and limit their consequences to persons and the environment' (COMAH regulation 4).

96 All major hazard sites are unique, but there are many common threads to the management of them. Many of the important factors are discussed in this document. They warrant careful consideration by the whole of the major hazard sector.

97 The types of managerial failings revealed during the Buncefield investigation were often found at other major incidents. The report on the gas explosion at Longford, Australia in 1998 (*Lessons from Longford: The Esso Gas Plant Explosion*[8]) identified factors associated with the incident which were also present at Buncefield. For example:

- poor communications at shift handover;
- lack of engineering expertise on site; and
- failure to implement management of change processes.

98 Equally, some of the failings identified at Buncefield were also identified by Baker[9] in his report on the explosion and fire at the Texas City Refinery in March 2005. Baker's report drew out findings of a similar nature. In both cases management failed to address safety critical process controls.

99 The Baker report emphasised that process safety protection systems should not rely on operator response to alarms and that overfill protection should be independent of normal operational monitoring. That lesson again must be drawn from the Buncefield incident. Further, both Baker and the MIIB suggest that leadership and top-level engagement in dealing with significant risks to people and the environment in this industrial sector was lacking.

100 The Buncefield explosion was therefore further evidence that the major hazard industries had still not taken on board vital lessons. This document aims to reinforce previous findings and serves as a further stimulus to improvements in process safety leadership; health, safety and environmental management; and control of major accident hazards.

Appendix 1 How the independent high-level switch (IHLS) worked

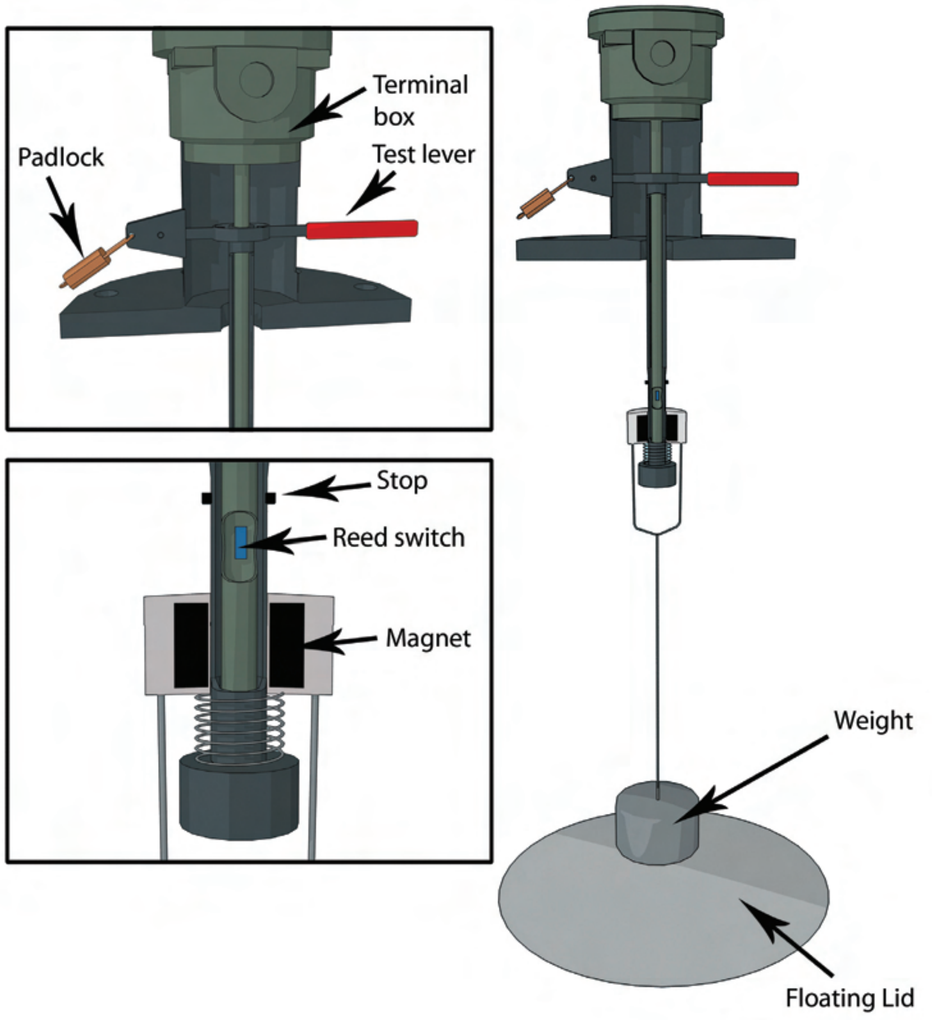

Figure 12 The working principles of the IHLS

1 The switch worked – ie activated the alarm circuit – when the floating internal deck (lid) contacted and raised the internal suspended weight. This in turn raised a magnet which activated a reed switch.

2 The check lever allowed the switch and the alarm circuit to be activated independently of the movement of the floating lid. In effect the checking action simulated exactly what should happen if the floating lid arrived at that point.

3 There were three positions for the lever. The horizontal position was the normal operating position. In this position the switch operates as expected, ie if the floating lid lifts the weight, so that it is no longer hanging from the switch, the reed switch changes state and this initiates an emergency shutdown. The IHLS installed in Tank 912 was designed so that a padlock should be used to secure the lever in the horizontal position.

4 To carry out the test, the padlock would be removed and the lever raised to the upper position. The alarm circuit would be activated even though the weight had not been lifted by the floating lid. On completion of the test, the lever would return to the horizontal position and the padlock would be replaced.

5 Because the switch could also be installed to detect low levels of fuel in a tank it could also work in the opposite mode. If installed in that way, the test would be carried out by lowering the check lever. Unfortunately, lowering the check lever when the switch was intended to operate in the high-level mode effectively disabled the switch. The purpose of the padlock was to ensure that in normal operating mode the check lever remained in the horizontal position and it was therefore a vital safety feature.

6 If the padlock was not replaced, it was possible for the check lever to be left in the lower position or to fall naturally. In either case the switch would be disabled.

7 Therefore, for the function sought on Tank 912 the lower position performed no useful purpose at all. While in other configurations it could have been used to detect low tank levels, this was not needed in this case. It follows that not only did the switch feature a potentially dangerous disabled position, which carried a risk that it would be inadvertently inoperable, but it was also a risk that was unnecessary to run.

8 After the Buncefield incident, TAV modified the design to incorporate a pin that prevented the handle travelling below the horizontal.

Appendix 2 Outcome of criminal proceedings

1 Five companies were charged with offences arising out of the investigation of the Buncefield incident. Proceedings were completed at St Albans Crown Court on 16 July 2010. The outcome was as follows:

2 Total UK Limited pleaded guilty to three charges:

- failing to ensure the safety of its employees so far as was reasonably practicable in breach of Section 2(i) of the Health and Safety at Work etc Act 1974, contrary to Section 33 of that Act. **Fined £1 000 000**;
- failing to ensure the safety of persons not in its employment so far as was reasonably practicable in breach of Section 3(i) of the Health and Safety at Work etc Act 1974, contrary to Section 33 of that Act. **Fined £1 000 000**; and
- causing pollution of controlled waters, contrary to Section 85(1) and (6) of the Water Resources Act 1991. **Fined £600 000**.

3 Hertfordshire Oil Storage Limited was found guilty of failing to take all measures necessary to prevent major accidents and limit their consequences to persons and the environment, contrary to regulation 4 of the Control of Major Accident Hazard Regulations 1999. **Fined £1 000 000**.

4 They pleaded guilty to causing pollution of controlled waters, contrary to Section 85(1) and (6) of the Water Resources Act 1991. **Fined £450 000**.

5 British Pipeline Agency Limited pleaded guilty to two charges:

- failing to take all measures necessary to prevent major accidents and limit their consequences to persons and the environment, contrary to regulation 4 of the Control of Major Accident Hazard Regulations 1999. **Fined £150 000**; and
- causing pollution of controlled waters, contrary to Section 85(1) and (6) of the Water Resources Act 1991. **Fined £150 000**.

6 Motherwell Control Systems 2003 Limited was found guilty of failing to ensure the safety of persons not in its employment so far as was reasonably practicable in breach of Section 3 of the Health and Safety at Work etc Act 1974, contrary to Section 33 of that Act. **Fined £1000**.

7 TAV Engineering Limited was found guilty of failing to ensure the safety of persons not in its employment so far as was reasonably practicable in breach of Section 3 of the Health and Safety at Work etc Act 1974, contrary to Section 33 of that Act. **Fined £1000**.

8 The Court ordered costs against the defendants totalling**£4 081 000**.

Glossary

ATG automatic tank gauging system.

BPA British Pipeline Agency Ltd.
bund usually a wall, or earth embankment, intended to contain fuel lost from a tank.

COMAH Competent Authority in England and Wales, the Health and Safety Executive and the Environment Agency, working jointly.
COMAH Regulations Control of Major Accident Hazards Regulations 1999 (as amended).

HOSL Hertfordshire Oil Storage Ltd, a joint venture between Total UK Ltd and Chevron Ltd.

IHLS independent high-level switch.

PFOS perfluorooctane sulphonate.
primary containment the tank in which fuel is normally stored.
PSLG Process Safety Leadership Group.

SCADA supervisory control and data acquisition. It generally refers to computerised systems such as those that monitor and control industrial processes.
secondary containment typically a bund, surrounding a tank or group of tanks.
soakaway permeable area of ground, or buried structure, designed to speed the drainage of clean surface water into the ground.

tertiary containment the means by which liquids can be contained/controlled within the site boundary.

UKOP UK Oil Pipelines Ltd.
ullage (or ullage space) the 'headspace' in a tank between the surface of the liquid and the tank's 'brim full' capacity.

waterstop preformed strips of durable impermeable material embedded in the concrete during construction providing a liquid-tight seal during a range of joint movements.

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