The Buncefield Accident

12/5/2010
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ABSTRACT

The Process failure that occurred at Buncefield site, Hertfordshire, UK was one of the landmark incidents in the process safety concerns of vapor cloud explosion. The vapor cloud that formed was due to overfilled large storage tank, containing unleaded fuel. The overflow of the tank was the result of a failed level indicating system and lack of operator's attention at the site. A legal investigation on the incident was carried out by Buncefield Major Incident Investigation Board (BMIIB), which presented the causes for the explosion and the recommendations for future prevention. The report briefly discusses the series of steps that led to the major incident. Prior to the Buncefield, a massive explosion on such scale was not predicted; hence the Buncefield incident breaches the worst case scenario that was predicted for vapor cloud explosion. The report also provides the explanation regarding why the explosion breaches the worst case scenario for predicted strength of the vapor cloud explosion. Moreover similar accidents are also presented along with the recommendations presented by Buncefield Major Incident Investigation Board.

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INTRODUCTION

The largest fire Europe has known since World War II occurred at the Hertfordshire Oil Storage Terminal, an oil storage facility located by Hemel Hempstead in Hertfordshire, England on 11 December 2005. The Oil Storage Terminal, with a capacity of 60,000,000 imperial gallons of fuel, was the fifth largest oil-products storage depot in the United Kingdom. It was co-owned by two companies; TOTAL and Texaco. Three other companies were also involved in the disaster, notoriously known as the Buncefield disaster.[1]

Like most damaging explosions, the Buncefield disaster consisted of a series of explosions; the first of which led to further explosions eventually shattered twenty large storage tanks. Investigations determined that a flammable cloud formed by overfilling and spillage of 300 tonnes of petrol by a storage tank which has been ignited resulting in explosion. Interestingly, what added to the intensity of the explosion was the presence of trees, which resulted in a larger overpressures producing severe property damage.[2]

The impacts resulting from the accident resulted in significant health, economic, and environmental damages. Even though the damage resulting from the accident has been exorbitant, and the fire burned for several days, not a single fatality was involved with the disaster. Unfortunately however, over forty people were injured.[3] In financial terms, these impacts cost the companies approximately nine million, and five hundred thousand Euros. The claimants included businesses, individuals, and local authorities. Although most of the claims were from individuals, the most costly ones were from the business organizations. As for the environmental impacts, this accident led to both air and ground pollution.

The severe impacts led to the Buncefield Major Incident Investigation Board (BMIIB) to investigate and record their recommendations to avoid such incidents from occurring in the future. Even with that, two similar accidents occurred not too long after Buncefield's: One in Puerto Rico, and the other in India.

THE BUNCEFIELD INCIDENT

Accident Site and Key Events

The Buncefield Depot

The Buncefield depot was opened over thirty years ago, in 1968, outside the town of Hemel Hempstead which was located approximately forty kilometers away from London, and close to the busy M1 motorway. Figure 1 below shows a map locating the Buncefield fuel depot in England. [3] This 50-acre fuel depot was the fifth largest storage site in England. [4] Approximately eight percent of United Kingdom's overall oil supplies, out of which twenty percent was consumed by southeast United Kingdom, were provided by the depot. [5] Buncefield depot used to store the fuels in large tanks before being transported to different refineries such as petrol stations and airports.

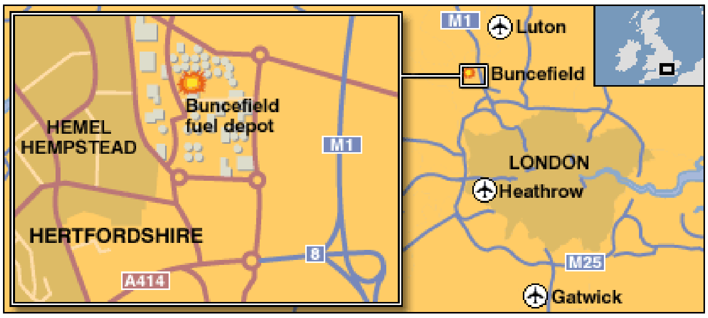

Figure 1: Buncefield fuel depot, England [4]

The Depot's sites

The Hertfordshire Oil Storage Terminal, also known as HOSL, delivered approximately 2.37 million metric tons of oil products a year by pipeline and tankers. This oil consisted of mainly petrol, diesel, and aviation fuels. [3] HOSL was a joint venture between Total and Chevron, and its east and west units made up forty percent of Buncefield.[5] There were two other sits in the depot: British Pipeline Agency Ltd (BPA), a joint venture between Shell and BP with

UK Oil Pipeline Ltd. and BP Oil Ltd, located south of the depot. Each site was allowed to store 70,000 and 75,000 of fuels respectively.[4]

Buncefield's Pipelines

Three different pipelines were extended from Buncefield depot to supply numerous refineries in the U.K.: Finaline, M/B pipeline, and T/K pipeline. [4] As a matter of fact, Buncefield supplied London Gatwick Airport, the second largest airport in the United Kingdom. Also one of the pipelines was specifically designed to supply approximately forty percent of the aviation fuel used at London Heathrow Airport, [5] U.K.'s first, and the world's third most active airport. [6]

The Incident

On Saturday 10 December 2005, petrol was being delivered through Buncefield's T/K pipeline to a tank, Tank 912 in bund A (Figure 2) [4], in the northwest corner of the site. [4] Usually, the gauges shown in Figure 3 take fuel level readings in the tank as it is being filled from a pipeline. In case the tank reaches its maximum volume limit, an automatic high level safety switch would activate an alarm, which then results in a system shutdown. Unfortunately, the safety system was not working at the time, and none of the workers realized that the filling has exceeded the tank's capacity. This resulted in fuel overflow through the roof vents. Investigators believe that the overflow occurred at around 5:20 am. [3]

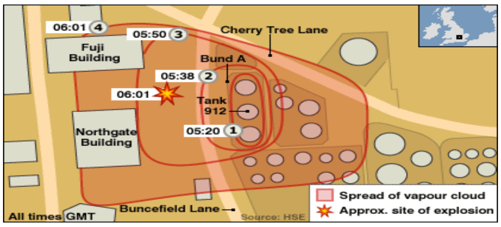

Figure 2: How the vapor spread at Buncefield [3]

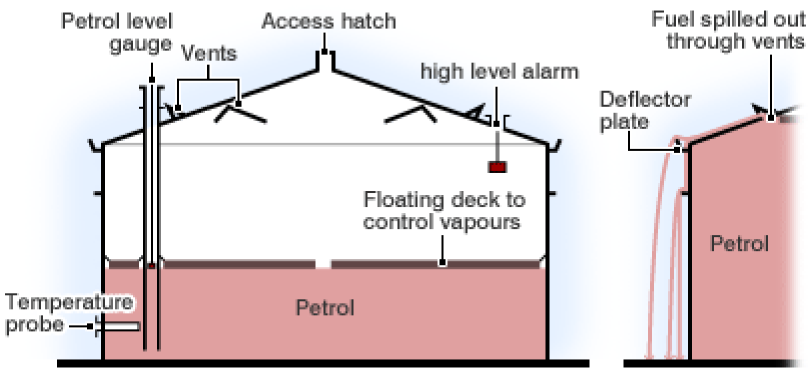

Figure 3: Tank 912 [3]

The overflow resulted in a formation of a vapor cloud rich in fuel and air at around 5:38 am. CCTV (Closed-circuit television) footages show the formation of a white misty cloud formation. (Figure 4) [4]. Although the exact composition and nature of the cloud is not known with full accuracy, investigators assumed that it might have been a volatile fraction of the original fuel, or ice formations that resulted from the chilled air as a result of the escaping fuel's evaporation. [4]

This cloud was initially approximately one meter deep; however it thickened until it reached around two meters, and started dispersing in different directions. Twelve minutes later, the vapor started drifting off near the site, close to the intersection of Cherry Tree Lane and Buncefield Lane. At 5:50 am, the rate of the fuel pumping into tank 912 was around 550 cubic meters per hour. In the next ten minutes, the rate increased to approximately 890 cubic meters per hour. [3] Normally, petrol does not explode easily, however over three hundred tonnes of petrol were released from the tank, out of which approximately ten percent turned to vapor that mixed with air. This resulted in the formation of a flammable mixture, or a vapor cloud with concentrations that are high enough to combust. [5] At 6:01 am, the vapor cloud blanketed a large area and reached the buildings next to the site where the first explosion occurred. [3]

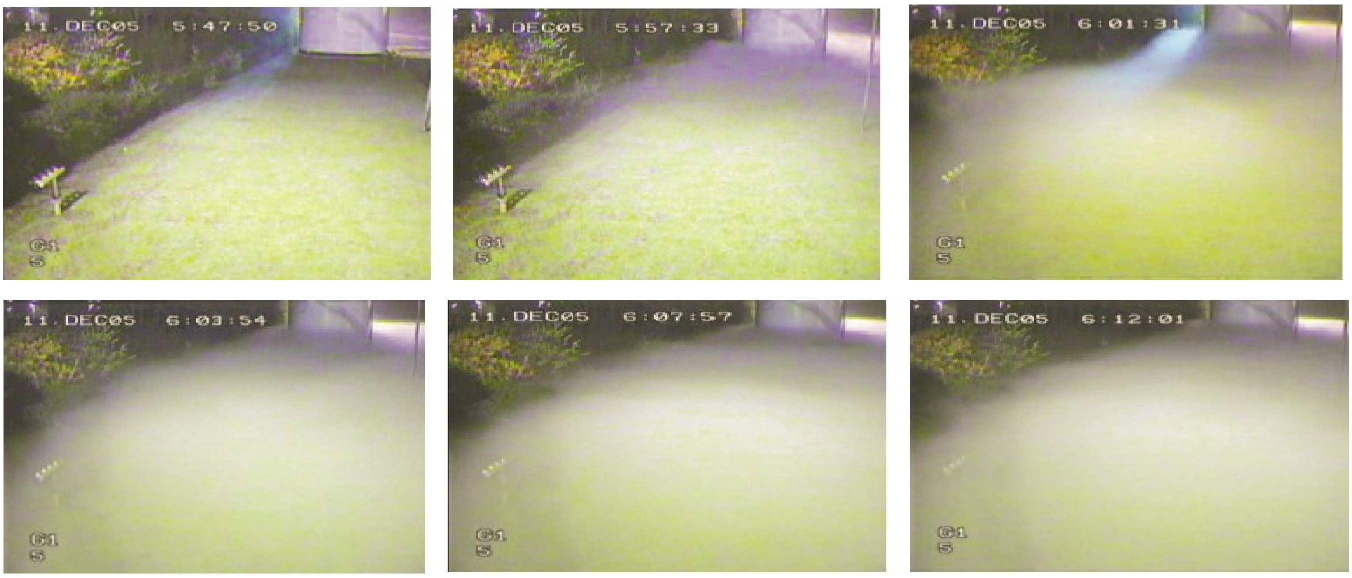

Figure 4: Images from a CCTV footage [4]

The first massive explosion lead to further explosions, causing a massive fire that submerged more than twenty large storage tanks over a large section of the Buncefield depot. After five days of the fire burning, most of the depot was destroyed. The evidence could be seen from many miles away, and in satellite images, as an outsized plume of black smoke, which after some time spread over southern England and beyond. [4]

A major emergency was announced by the emergency services at around 06:08 am, and a firefighting effort began. Twenty five fire engines, twenty support cars, and around one hundred and eighty firefighters were on the site before the flames were put down on the fifteenth of December. [3] Around one thousand firefighters were involved in putting down the flame. It took thirty-two hours to extinguish the main fire, although a few smaller tanks were still ablaze on Tuesday the thirteenth of December. A new fire began on the following day in an intact tank, but the emergency service let allowed it to burn out safely. The firefighting maneuver utilized approximately 750,000 liters of foam concentrate, and 55 million liters of water. Also, over two thousand people had to evacuate their houses during the emergency operation, and some of the motorway sections had to be closed. A few schools in Hertforshire, Buckinghamshire, and Bedfordshire were shut down for two days after the explosion.[3]

After putting out all the fire on the fifteenth of December, a specialist investigation team from the Health and Safety Executive (HSE) and the Environmental Agency were given the task of analyzing what had caused the accident in the first place. A few days later, some of the damaged areas on and around the site were cleaned up. However, some sections of the site were still too dangerous for the investigators to access them for days, weeks, and sometimes months afterwards. [3]

What Makes This Explosion Unusual?

What made the main explosion unusual amongst other vapor cloud explosions is the high overpressure that was associated with it. [4] The third of three progress reports from the BMIIB states that "The magnitude of the overpressures generated in the open areas of the Northgate and Fuji car parks is not consistent with the current understanding of the vapor cloud explosions". At this point, Gexcon's investigation with Total helped in finding the mechanisms underlying the severe Buncefield explosion. [7]

High Overpressure

"As a definition, the term overpressure refers to the pressure increase in the vessel over the set pressure during the relieving process. It is equivalent to the accumulation when the set pressure is at the maximum allowable working pressure, or the maximum gauge pressure allowed at the top of a vessel for a certain temperature. [8] In simple terms, it is the transient air pressure that is greater than the surrounding atmospheric pressure. [9]

The question remains as to what caused this overpressure? Initially, Gexcon performed a survey on the remnants of the Buncefield oil storage depot in June 2006. From this survey, it was found that the congestion that was present in the tank fire was not adequate enough to cause the high overpressure that had occurred. However, when the area of the Buncefield accident was examined, it lead to the theory that the trees and the undergrowth along two roads enclosing the site formed the significant congestion that was responsible for the flame's acceleration and therefore the high overpressures in the flammable cloud [7].

Figure 5: Undergrowth and Trees Surrounding the Site[7]

In order to further support their theory, Gexcon modeled the oil depot and the surrounding suspect tree areas using FLACS, the explosion and dispersion simulator. Simulations of the explosions of the large vapor cloud performed showed that when the trees were incorporated into the model, a very high overpressure was generated. In some cases, the overpressure exceeded 10 bars, a value large enough to explain the damage caused. However, when the simulation was repeated without trees, a very low overpressure was obtained; sometimes below 0.1 bar.[7]

Unfortunately, since the size, location, and composition of the vapor cloud were not obtainable, the simulation of the true representation of the actual explosion that took place was prevented. However, when the code was applied to the Buncefield case it produced realistic results. Although this is not proof enough to state that the trees were the sole reason for the high overpressures, work presented in 2009 by the Fire and Blast Information Group (FABIG) supported Gexcon's conclusion that the trees played a vital role in developing Buncefield's explosion.[7]

IMPACTS OF THE ACCIDENT

The Buncefield Incident had many impacts which cost the company £1 billion. This money was spent on three areas: Economical, environmental and health-related damages.[4]

Financial impacts

Economically there were three major impacts. The first one was the cost of the incident itself. The total cost of the incident was estimated to be approximately £1 billion. More details on the cost are shown in table 1 below. [4]

Table 1: Overall cost of the UK incident

Sector Cost	(£ million)
Site operators (compensation claims)	£625
Aviation	£245
Competent Authority and Government response	£15
Emergency response	£7
Environmental impact (drinking water)	£2
Total	£894

From Table 1, it is shown that out of the five different sectors, the most costly one was regarding the site operators. Table 2 includes more details regarding the costs of the business, individuals, and the local authorities that were involved in the accident. These include claims directed from individuals who were evacuated from their houses during the fire, and the damages that were pertained to the damages inflicted as a result of the explosion. [4] Those damages were mostly broken windows, door frames, roofs and cracks in walls. Fortunately, with these minor damages did not cause the house prices to decrease. While some of the individuals were fortunate enough to be far from the accident site, some of them residing nearby suffered major structural damages. Some people got their claim from their insurance companies, while others still did not receive them.[10] The total amount of money presented in Table 2 below does not include the price of rebuilding the incident site. [4]

Table 2: Business, individuals and local authorities cost.

Type	Number	Cost Million (£)
Business		
• **inside site perimeter**	5	103£
• **outside site perimeter**	749	188£
• **Subtotal businesses**	754	591£
Individuals	3379	30£
Local authorities	7	4£
Total	4140	625£

Although most of the claims were from individuals, the most costly claims were from the business organizations. Approximately fourteen businesses were relocated, and several others started operating from temporary sites. Also, two businesses have gone into bankruptcy. Those number of businesses amounted to 630 firms, 90 of which are companies with 16,500 employees. The cost of the people losing their jobs was estimated to be £10 million. [4]

Not only did the accident affect the buildings surrounding the site, but another major part of the community was affected: the Heathrow Airport. The airport stopped working for a period of time because the Buncefield used to supply the airport with 21 million liters of fuel daily. As a result, the airport had to arrange for other delivery method to refuel the planes; long flights stopped at other nearby airports, whereas the short flights refueled their planes before flying to Heathrow. [4]

Environmental Cost

The environmental impacts caused pollution damage. These were categorized into two major types: air and ground pollution. No sufficient details can be found regarding the exact figures involved with the air pollution. The ground pollution, on the other hand, cost £2 million. [4]

Approximately twenty six million liters of water were used to fight the fire. The water that was used to fight the fire was then stored. Unfortunately, eighty thousand liters of this stored water was found to have leaked into a tributary of the river Thames. This water contained toxic materials that do not decompose in the ground. In order to avoid more contamination, the £2 million were used to treat the water and make sure that it does not contain any toxic materials. [10]

Personal injuries

Although there were no deaths, there were forty-three injuries reported. Those injuries were minor, and not life threatening. [4]

SIMILAR INCIDENTS

After such a massive accident, one would think that people would learn from their mistakes. Unfortunately, this did not happen. More than one Buncefield-like accident occurred after this massive catastrophe. In the paragraphs that follow, two incidents will be summarized. One occurred in Puerto Rico, and the other in India.

In October 23, 2009 a massive explosion and fire occurred in Puerto Rico near San Juan. More than half of the fuel depot's tanks (forty tanks) were burned. The fire lasted three days and many businesses and houses were burned. The incident was also a result of overfilling of a tank, which did not even have a monitoring system. As the gasoline started to spill from the tank, it vaporized and formed a vapor cloud approximately 2000 feet (610 meter) above the ground. The flammable vapor cloud ignited as soon as it got in contact with an unknown ignition source.[13] Luckily enough, no one died as a result of this incident (only one person was taken to the hospital and 350 people were evacuated). The incident cost $6.4 million.[14] From the information presented, this accident was caused by the same reasons that led to the UK incident, and it can be clearly seen that the industry people did not apply the recommendations presented from the Buncefield fire.

Figure 6: Buncefield fire in Puerto Rico. [14]

The other similar incident occurred in Jaipur, India, where the fire lasted for eleven days. Although the accident was also a result of tank overfilling, it was more careless than the previous ones as the workers bluntly overlooked all the signs of a hazard occurring. Reports reveal that alarms started and the smell of oil was detected, but the workers chose to withhold this information from the officials until it became out of anyone's control. [11] Eleven tanks were burned out, and five workers died at the work site and many other were transferred to the hospital. [12]

Figure 7: Buncefield in Jaipur, India.

RECOMMENDATIONS

The BMIIB provided a detailed analysis of the Buncefield accident, as well as a report containing recommendations in order to improve the safety in the design and operation of fuel storage sites. The commission came up with many recommendations. These were classified under three main categories, and will be elaborated upon in the following sections.

1. Recommendations on land use planning and the control of societal risk around Buncefield.
2. Recommendations on emergency preparedness and response to and recovery from the incident
3. Recommendation on the design and operation of fuel storage sites

Land use planning and the control of societal risk around Buncefield

Land use planning includes the location of on-site and off-site developments. This involves engaging the technical panel to derive risk zone contours. The planning authorities take decisions on planning by taking into account the interests of the local community, the developer and relevant safety and environmental considerations. The advice from BMIIB includes the developments within the consultation distance of major hazard sites[16].

Societal risk is a measure of hazards that might affect people. It takes into account the total population at a potential risk. Even in areas where the individual risk is low, societal risk can still have significant impacts that cause it to be the main driver for risk reduction measures. Buncefield incident was fortunate to have no fatalities; however there was intense public reaction due to the extreme damages that were caused. The key recommendations on the land use planning and control of societal risk include the following[16]:

- Improvements in defining major hazard scenarios at flammable storage sites
- Improving the recording and sharing of incident data
- Improvements in investigating root causes of the incidents

The primary method of determining the human hazards was measured by the ‘dangerous dose or worse’ assessment. In this risk assessment, the hazard criteria are defined in terms of a dangerous dose of toxic, or heat, or explosion overpressure[16]. As a definition, the dangerous dose is one which gives rise to one or more of the following effects[22]:

A. Severe distress to almost everyone
B. A substantial fraction requires medical attention
C. Some people are seriously injured, requiring prolonged treatment
D. Highly susceptible people might be killed

This form of risk assessment was a weak link to determine individual risk. Hence a new method of risk evaluation was proposed based on ‘risk of fatality’. Risk of fatality is based on annual probability that a fatality might occur[16].

Emergency Preparedness and Response to and Recovery from the Incident

This section mainly highlights recommendation on the operations as a response to the incident , and the location of the recovery equipment. After the explosion had occurred, the two pump houses and their associated lagoons to the north and northwest of the site were rendered unavailable for use as it was blocked by the explosion. This could have been prevented by relocating the pump houses to a safer and more accessible location. Alternative arrangements must also be present in case primary response facilities become unavailable[21].

Other ways in which the response to the incident could be improved is the introduction of an alternative passage through which the crew members could be evacuated and additional support in terms of fire fighting[21].

In addition to the mentioned recommendations, seasonal variations must also be taken into account. For example, the main water source for fighting the fires at Buncefield was the Breakspear Lagoon, which may not have held sufficient water during summer. Hence ensuring the proper water level in the tank is one of the important issues in the emergency preparedness[21].

The Design and Operation of Fuel Storage Sites

In brief the recommendation based on the design and the operation of fuel storage sites emphasize upon the need to increase the protection provided by primary containment systems. The primary means of containment were the tanks, pipes and vessels that hold liquids and the devices fitted to them, in case of an emergency to allow for safer operations until the issue is taken care of. The incident at Buncefield occurred due to the failure of the primary containment system, which allowed the overfilling of a vessel, resulting in the formation of large flammable vapor cloud that subsequently ignited[20].

The effective means of preventing environmental pollution in the event of a failure of primary containment must be covered by secondary and tertiary containment systems in order to operate within safety limits. The Secondary means of containment consist of enclosed areas around storage vessels (often called bunds), created usually by concrete or earth walls. Their purpose is to hold any escaping liquid or chemicals used in firefighting. Tertiary means are features such as drains designed to limit the passage of chemicals off the site, raised kerbs to prevent liquids that have breached the bunds from escaping into the general area around the site. Moreover safety equipment must be proof tested before implementation[20].

Protecting against loss of primary containment using high integrity systems

According to the commission, protection against loss of primary containment system could be dealt with by ensuring the integrity of the containment system. To ensure integrity, an independent overfill prevention systems must be installed at sites handling large quantities of highly flammable liquid[20].

Moreover, in the event of transferring the flammable liquid, proper communication must be done between the parties responsible of transferring the fuel between the sites and refineries. This mainly involves the communications between site operators and operators of pipeline transfers[20].

The other aspect on the protection against primary containment includes fitting of automatic operating overfill prevention that is physically and electrically separate and independent from the tank gauging system. Moreover, an arrangement must be made to ensure the receiving site has control of tank filling i.e. the receiving site should be able to safely terminate or divert a transfer (to prevent loss of containment or other dangerous conditions) without depending on the availability of communications with the remote location. Hence in case of emergencies, the time delay could be prevented by not relying on communications from the transferring sites[20]. The following Figure 8 shows the schematic diagram of a typical internal floating roof tank[19].

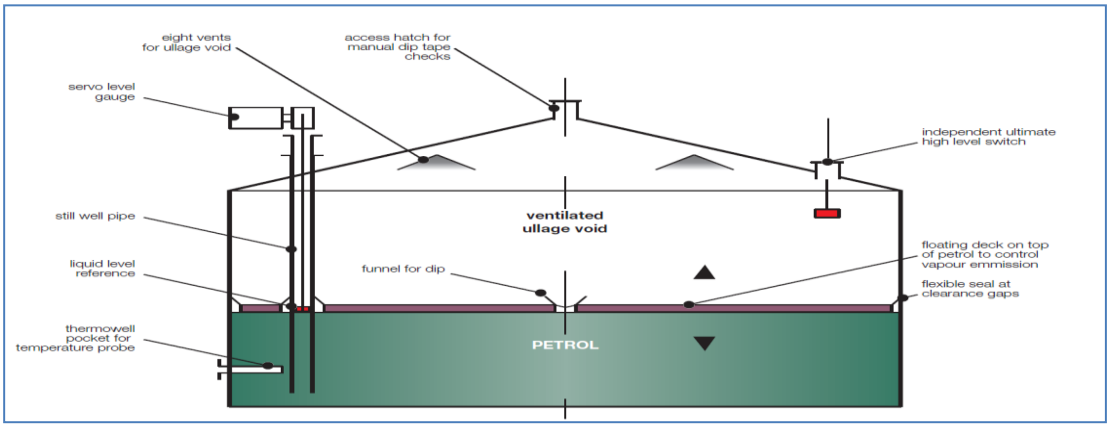

Figure 8: Diagram depicting the internal floating roof tank

According to the recommendation, the roof tank could be employed with an independent ultimate high level switch (upper right on figure 1). In the situation of power cutoff, the high level switch keeps functioning to monitor the safe level of the tank. The tank capacities fill levels and safety margins must also be clearly determined for all fuel storage tanks. To prevent an overflow, tanks should have headspace devices that enable the filling line to be closed off in time. The set points of high level trips and alarms should allow sufficient time for the action to be taken to deal with the developing situation[17].

Having established the overfill level (maximum capacity), it is then necessary to specify a level, below an alarm sounds and allow sufficient time to take safety measures. This is known as the 'tank rated capacity'[17].

The prevention of the secondary containment equipment failure could be achieved by the following procedures:

- Detecting high levels of vapor in secondary containment is an early indication of loss of primary containment. This failure should initiate action to limit the extent of any further loss of material. This can be achieved using an overfill prevention system[20].
- Bunds should have no pipe work that penetrate through the bund floors or walls, they should also have sufficient capacity to allow for tank failure and firewater management, and they should be capable of withstanding the full hydrostatic head of liquid that may arise from the loss of primary containment[20].
- Installing CCTV equipment to assist operators with early detection of abnormal conditions. Operators cannot routinely monitor large numbers of passive screens, but equipment is available that detects and responds to changes in conditions and alerts operators to these changes[20].

Tertiary containment is independent of the primary and secondary containment systems. These include site drainage systems and sumps, diversion tanks, impervious liners and/or flexible booms. Tertiary containment will be utilized when there is an event that causes the loss of primary and secondary containment (bund joint failure or firewater overflowing from a bund during a prolonged tank fire) [19].

DAMAGE COST VERSUS COST WITH SAFETY EQUIPMENT

The Board recommendations included several solutions to prevent a major incident like the Buncefeild. The basis for these calculations is that of a typical site operation containing ten tanks. Three solutions were evaluated:

1. The placement of an automatic shut-off valve in the inlet pipe to the site to prevent the fuel from flowing to all the tanks on the site. This solution's cost is estimated to be £23 million.
2. The placement of an automatic shut-off value in each pipe tank inlet to prevent fuel flow between tanks and from one tank to another. It can also be a solution to isolate the tank is case of a fire. This solution costs approximately £82 million.
3. The placement of two automatic valves in each tank; One in the inlet and another in the outlet to prevent the fuel from flowing between tanks. It will also isolate the tank in the case one of the valves' failure. This method costs around £167 million.

As shown, the cheapest solution to prevent a major Buncefield-like accident costs £23 million. If compared to the total cost of the damage caused by the entire Buncefield accident (£1 billion), one can see how much money a company can save even if it incorporated the most expensive safety system.

CONCLUSION

In December 11, 2005 a huge explosion occurred in Hertforeshire, England, the fifth largest oil-product storage in the United Kingdom. Although it began with one massive explosion, it resulted to a series of explosions that led to severe damages. The incident was initiated because of the overfilling and spillage of fuel in one of the tanks. This lead to the formation of a flammable cloud that was ignited by an unknown ignition source. What made this incident even worse was the large overpressure associated with it. Further studies and experimentations showed that this occurred due to the presence of trees.

The accident resulted in economic, heath and environmental impacts. Many businesses suffered from damages that lead to their relocation, and others had to shut down. This caused many people to lose their jobs. Although no one died in the accident, many people were injured and had to be transferred to the hospitals. Environmentally, some of the water that was used in the fire fighting operations was found to be leaking to a tributary of the Thames, causing ground pollution. As a result, the company started treating the stored water, costing them even more money. When the cost of the impacts were compared with the cost of incorporating safety equipment in the process, it was found that the cost of adding safety tools was a lot less than the cost resulting from the damage. This leads to the generalization that inherent safety will not only save time and effort, but money as well.

These impacts led to a major investigation by the Buncefield Major Incident Investigation Board (BMIIB). The recommendations given by them were made to avoid the recurrence of similar accidents. Unfortunately, not many companies learned from these mistake. Two similar accidents occurred not too long after Buncefield's: One in Puerto Rico, and the other in India.

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