# EXAMPLE REAL LIFE FIRES AND EXPLOSIONS

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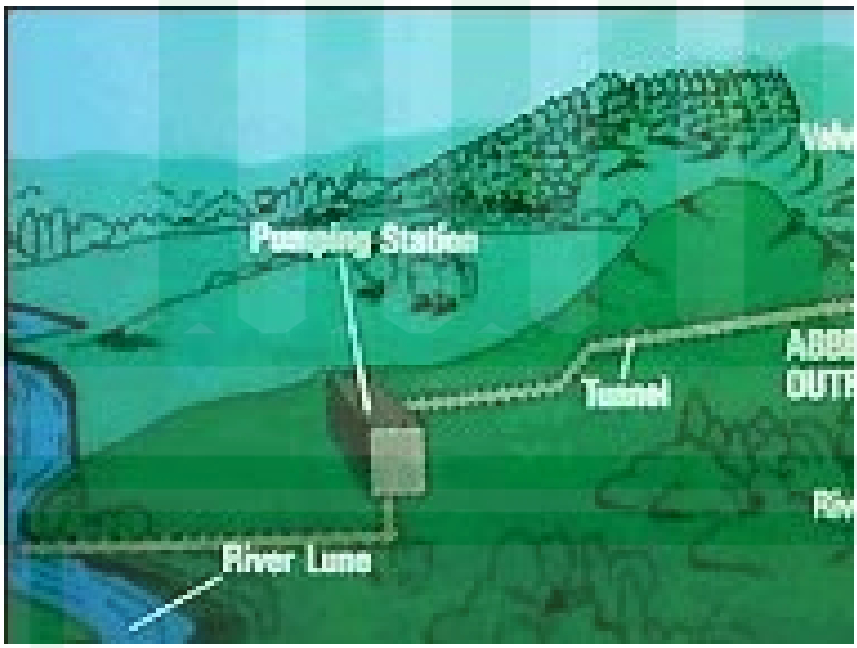
## ABBEYSTEAD, 1984 - Confined (Space) Vapour Cloud Explosions

On the evening of Wednesday 23rd May 1984 a group of 44 people including 8 employees of the North West Water Authority assembled in a valve house at Abbeystead. At 7.30 p.m a massive explosion ripped through the building; 16 people were killed and 28 were seriously injured.

The Lancaster River Authority had commissioned a firm of engineering consultants, Binnie and Partners, to design a system to transfer water from the rivers of the northern part of the country to south Lancashire. The Wyresdale Transfer Scheme was designed in the early 1970s. It was to be the initial stage of a larger scheme and its purpose was to transfer water over a distance of 11.6 km between the River Lune at Lancaster to the River Wyre at Abbeystead.




The designers, Binnie and Partners, had to take into account a number of design considerations. As might be expected, cost was a significant factor. At the same time, the scheme was to be located in an area of natural beauty and therefore the design had to take into account environmental concerns related to its preservation. Binnies also had to design for the security of the installation and to protect the valves from adverse weather conditions. The construction contract was awarded to Edmund Nuttall Ltd and work began at the end of the year. Work was completed in early 1979 and water transfer began in 1979 under the organisational control of what is now the North West Water Authority (NWWA). The Factory Inspectorate visited the installation in July 1981 and effectively designated it a ‘low-risk’ establishment.

From the time the scheme became operational there was increasing concern in the village of St.Michaels-on-Wyre, downstream from Abbeystead. Heavy flooding in the village had led villagers to wonder if the problem may have been caused by the transfer system. The NWWA were anxious to demonstrate that this was not the case and therefore invited a group of villagers to inspect the Abbeystead scheme and to see a demonstration of the pumping system in operation. The events of that fateful evening are as follows: at 7.00 p.m. the visitors were admitted to the valve house, a concrete building set into the hillside; at 7.12 p.m. pumping was started. The visitors waited to see the water come through. By 7.22 p.m. no water had yet reached the valve

house. A phone call was made to the pump operator to double the speed of the flow.

At 7.30 the building was blown apart by a huge explosion. Those who were not killed instantly were badly injured from explosion injuries, burns and the collapse of the heavy cement roof. At 7.40 p.m. the first flow of water reached the valve house. Local residents who had heard the explosion reached the scene and alerted the emergency services. At 7.48 p.m. the first ambulances arrived at the scene of the disaster and at 7.50 p.m. the pump operator was contacted by telephone and told to check the water flow because of the explosion. The pump operator thought the call was a hoax and rang back for confirmation. At 8.05 p.m. the pumps were turned off. The dead and injured were taken to hospitals in Lancaster and Preston and by 6.00 a.m. the following morning salvage operations were completed.

Later that day (24 May 1984) the first inspection of the site of the disaster was made and preliminary investigations concluded that the explosion was caused by the ignition of methane present in the valve house. It was thought that methane had collected in a void in the tunnel and that when pumping started, the volume of water in the tunnel pushed the methane into the valve house. A match or a spark was thought to have been the immediate cause of the explosion.

The Times, on 25 May 1984 also speculated on methane as the cause arguing that ‘the location of the pumping station in the Forest of Bowland suggests a likelihood of methane’. The article continued that some coal was known to exist in parts of the underground area through which the station’s pipeline ran at depths of as much as 500 ft.’ An official inquiry was started almost immediately with the two-fold objective of discovering the cause of the disaster in order to avoid future similar accidents and, secondly, to attempt to determine who was to blame for the accident. The Health and Safety Executive brought in a team of many more experts in the preparation of background reports. NWWA carried out its own internal investigation to which Binnie and Partners were asked to report.

In October 1984 the Inspector of Factories produced a report indicating that the methane found at the site of the disaster was of ‘ancient origin’, that is, was millions of years old. In the same month, an inquest on the victims concluded that the explosion of methane had been an unforeseeable accident. The Health and Safety Executive (HSE) Report in the early part of 1985 confirmed this conclusion. The report found that methane and air had accumulated in the tunnel void over the period of seventeen days immediately before the explosion when the tunnel was not in use.

When operations commenced on the evening of 23 May and water entered the tunnel the lethal mixture was pushed into the valve house where it had been ignited. The report drew attention to shortcomings in the design which allowed gases from the water tunnel to be vented into an enclosed valve house and not to the open air. This had been done partly to satisfy environmental considerations and partly because the presence of methane had not been suspected. The presence of ventilation grids in the outside wall of the valve house had not been adequate to the task of dispersing the large amount of gas which had accumulated on the night of the explosion.

A further factor was brought about by the fact that the NWWA had failed to keep the tunnel full of water as the designers had originally intended. This practice was outside the specifications of the operating manual supplied by Binnies but had been introduced for environmental reasons by those NWWA workers directly responsible for the operation of the scheme. Basically, they had a problem with a wash-out valve at the outfall-end of the tunnel at Abbeystead. This was intended by the designers to be opened from time to time to flush out the system. When the system was operated properly silt was able to build up which discoloured the River Wyre when the valve was flushed. Consequently, water authority

workers had adopted the practice of leaving the valve partly open to permit a constant trickle of water into the river.

Senior management were unaware of this practice. The consequences of these informal methods had not been considered by those involved. These two factors, design and operational practice, taken together had allowed a large volume of methane to develop. The immediate cause of ignition was not identified. However, smoking by visitors or staff had not been prohibited and this may have triggered the explosion. At the same time, it could have been caused by a static spark, as for example, when someone removed a garment made of a man-made fibre.

The inquiry did not allocate blame. The report argued that the solubility of methane in water had not been fully understood by the parties involved nor by the water industry in general. The civil engineering profession had not benefited from reports on the dangers of methane. Where reports had been published they had not been widely circulated or publicised. The HSE recommended that in future this should happen and argued for venting in similar water transfer schemes to be to a safe place, for regular monitoring for gas during construction, for safe systems of working to be laid down and for all procedures to be regularly monitored.

**Failings identified included**

The possibility of a methane rich atmosphere was not recognised, this also dissolves in water making it possible to leak into the system. A system of discharging water to an open atmosphere would have prevented the explosion.

There were no gas detectors. The design of the plant was not in accordance with the operating manual, changes in operating procedures had taken place i.e. not using the pump all the time.

Causes

- A void had formed in the tunnel connecting the valve house to the pumping station.
- The void arose because a valve was left partly open, because of silting problems, regardless of whether pumping or not. Contrary to design rules.
- Geographical methane gas built up in the void.
- When pumping started the methane gas in the void was pushed to the vent chamber which then vented to atmosphere through the valve house rather than through a vent stack.
- Ignition of the gas may have been by smoking materials or electrical equipment.

## ALBRIGHT AND WILSON - AVONMOUTH 1996

## TOXIC FIRE DUE TO DELIVERY ERROR

A tanker, supposedly carrying epichlorohydrin, was being unloaded at the Albright and Wilson site in Avonmouth near Bristol. Several weeks earlier the company had received a certificate from the suppliers confirming the serial number of the tank container in which the substance would be delivered.

At some point between leaving the suppliers on mainland Europe and its arrival in Avonmouth, the wrong tanker had been connected up resulting in a different substance (and tank serial number) actually being delivered. This tank contained sodium chlorite which is highly reactive when mixed with epichlorohydrin.

By the time the error was realised unloading had already started to take place. This resulted in a series of explosions which destroyed both the tank and the delivery vehicle. In addition a cloud of toxic smoke 100m high caused the closing of the local motorway and railway lines.

On investigation it was revealed that no cross checking was carried on site before deliveries were unloaded. Had the paperwork been checked it should have been spotted that the wrong serial number was on the tanker.

The company was fined £60,000 whilst the damage to plant was estimated at £10 million.

## BRADFORD CITY FIRE – Football Club

Following the fire on 11 May 1985 at the Bradford City football ground where 56 people died and many were seriously injured, a committee was set up to enquire into the operation of the Safety of Sports Grounds Act 1975. The recommendations made in their final report resulted in changes introduced in the Fire Safety and Safety of Places of Sport Act 1987 and the revision of the Home Office Guide to Safety at Sports Grounds.

'A club's day of celebration is turned into tragedy'

Supporters of Bradford City FC were happy on Saturday 11th May 1985 as they made their way to the club's Valley Parade ground. The small unfashionable West Yorkshire club had already gained promotion to the Second Division and the last home game of the season against Lincoln City was to be something of a celebration. A larger than usual crowd turned up that day and once the match had started, the gates into the ground were locked to prevent anyone getting in free. There was a carefree atmosphere as the game neared half time. Then fans sitting at the back of the main grandstand noticed smoke curling up from beneath their seats. At first it was thought that it was minor thing – perhaps a carelessly dropped cigarette end, nothing to worry about. Then they realised that the fire was taking hold and panic spread as the people desperately tried to escape.

Television cameras were at the ground to record Bradford's hour of triumph, and found themselves recording instead the last terrible moments of fans lives, as the fire raced through the old grandstand with frightening speed. The stand roof caught fire and dropped blazing chunks of felt onto people below.

By the time the fire brigade arrived it was too late to save the victims. The grandstand was a mass of flames. There were no fire extinguishers nearby – the club had them but they had been removed to the main clubhouse after fans used them as missiles and set them off deliberately in the past.

Once the fire was extinguished, the grim task of recovering the bodies started. They were so badly burned that they could only be identified by meticulous examination of dental records and other forensic techniques. The only victim identified on the day of the fire was Samuel Firth aged 86, a lifelong supporter and former chairman of the club. The final death toll was 56, including some children: one 11-year-old died with his father, grandfather and uncle. Over 200 were injured, many with severe burns.

An investigation established that the fire started in accumulated rubbish piled under the grandstand and not cleared for many years. Possibly ignited by a dropped cigarette, it burned rapidly and fiercely, and with much of the stand being wooden, there was little to check the spread of the fire. It ran the whole length of the stand within ten minutes.
There was great shock expressed that a sports arena could be so ill-equipped to deal with a major fire, but it seems simply to have been an eventuality that no-one had considered. The Bradford fire led to demands for safer stadium, and the safety regulations were changed, but too late for the 56 who died and for those badly injured on that awful Saturday afternoon.

**BUNCEFIELD – Extract from 3rd progress report (UCVCE)**

This report describes where and how fuel escaped from storage at the Buncefield Oil Storage Depot on 11 December 2005 and how it vaporised, forming a flammable mixture that subsequently ignited at around 06.00 that morning with devastating consequences. It summarises the work carried out to analyse the electronic records that were recovered from site and experimental work undertaken by the Health and Safety Laboratory (HSL) to explain what happened to the fuel after it was released. So the heart of this report is a narrative, setting out the sequence of events leading up to the explosions.

For the complete picture of what is now known, this report should be read in conjunction with its predecessors, the details of which are not repeated here (see www.buncefieldinvestigation.gov.uk). The first progress report, published on 21 February, described in some depth the incident and emergency response. It concluded that the escape of fuel came from the area around bund A at the north west of the site and set out what was then known about the nature of the explosions and fire. The second progress report, published on 11 April, focused mainly on the environmental impact of the incident, and reported on the failure of some of the bunds to contain the fuel, foam and fire run-off water. It also set out the measures in hand to monitor any potential pollution levels.

**Timeline of events - *10 December 2005***

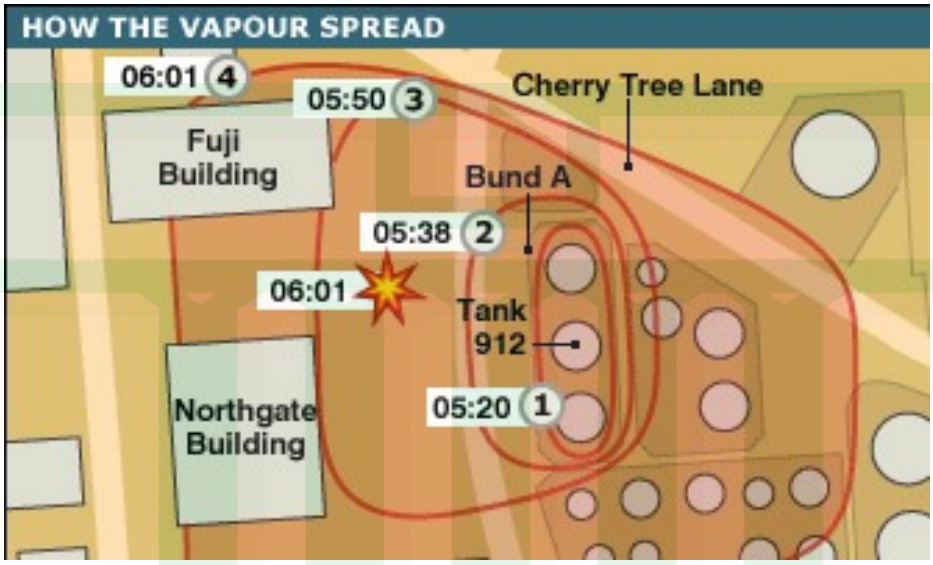
Around 19.00, Tank 912 in bund A at the HOSL West site started receiving unleaded motor fuel from the T/K South pipeline, pumping at about 550 m3/hour (flow rates are variable within limits).

***11 December 2005*** At approximately midnight, the terminal was closed to tankers and a stock check of products was carried out. When this was completed at around 01.30, no abnormalities were reported. From approximately 03.00, the level gauge for Tank 912 recorded an unchanged reading. However, filling of Tank 912 continued at a rate of around 550 m3/hour. Calculations show that at around 05.20, Tank 912 would have been completely full and starting to overflow. Evidence suggests that the protection system which should have automatically closed valves to prevent any more filling did not operate.

From 05.20 onwards, continued pumping caused fuel to cascade down the side of the tank and through the air, leading to the rapid formation of a rich fuel/air mixture that collected in bund A. At 05.38, CCTV footage shows vapour from escaped fuel start to flow out of the north-west corner of bund A towards the west. The vapour cloud was about 1m deep.

At 05.46, the vapour cloud had thickened to about 2 m deep and was flowing out of bund A in all directions. Between 05.50 and 06.00, the pumping rate down the T/K South pipeline to

Tank 912 gradually rose to around 890 m3/hour.




By 05.50, the vapour cloud had started flowing off site near the junction of Cherry Tree Lane and Buncefield Lane, following the ground topography. It spread west into Northgate House and Fuji car parks and towards Catherine House.

At 06.01, the first explosion occurred, followed by further explosions and a large fire that engulfed over 20 large storage tanks. The main explosion event was centred on the car parks between the HOSL West site and the Fuji and Northgate buildings. The exact ignition points are not certain, but are likely to have been a generator house in the Northgate car park and the pump house on
the HOSL West site.

At the time of ignition, the vapour cloud extended to the west almost as far as Boundary Way in the gaps between the 3-Com, Northgate and Fuji buildings; to the north west it extended as far as the nearest corner of Catherine House. It may have extended to the north of the HOSL site as far as British Pipelines Agency (BPA) Tank 12 and may have extended south across part of the HOSL site, but not as far as the tanker filling gantry. To the east it reached the BPA site.

**Buncefield Prosecutions**

St Alban's, UK – Five companies have been ordered to pay £9.5 million for their part in the 2005 fire and explosion at the Buncefield Oil Storage Depot, in Hertfordshire. The ruling included £1.3 million in fines for pollution offences – a record for a single incident in the UK – while a £3-million fine for Total was the second highest to be handed down for safety offences.

The fines, however, pale into insignificance compared to Total's estimated liability of up to £750 million for damages related to the incident at the Buncefield oil depot in December 2005.

Concluding a four-month trial at St Albans Crown Court, Mr Justice Calvert-Smith said the companies had shown "a slackness, inefficiency and a more or less complacent attitude to safety."

The prosecution of Total UK Ltd, British Pipeline Agency Ltd (BPA), Hertfordshire Oil Storage Ltd (HOSL), TAV Engineering Ltd (TAV) and Motherwell Control Systems 2003 Ltd, followed the most complex investigation ever conducted by the Health and Safety Executive and Environment Agency.

Oil giant Total UK Ltd pleaded guilty to three offences and was fined £3.6 million (£3million for safety; £600,000 for pollution) and ordered to pay costs of £2.6 million.

Supply company British Pipeline Agency Ltd pleaded guilty to three offences and was fined £300,000 for environmental offences and ordered to pay costs of £480,00

Hertfordshire Oil Storage Ltd was found guilty of two offences and fined £1.4 million (£1million for safety; £450,000 for pollution) with costs of £1 million

TAV Engineering Ltd, which designed a crucial safety switch that failed, was found guilty of one offence, fined £1,000 and ordered to pay £500 costs

Installation and maintenance company Motherwell Control Systems 2003 Ltd fined £1,000 and ordered to pay costs of £500 after being found guilty of one offence.

The investigation uncovered a series of serious failings that led to thousands of gallons of petrol being released in a large vapour cloud. The resulting explosion registered at 2.4 on the Richter scale, injured 43 people, destroyed nearby businesses and caused signifficant environmental damage.

The cost of dealing with the disaster has been estimated at more than £1billion, making it the most costly industrial incident in the UK.

Kevin Myers, HSE's deputy chief executive, said: "Incidents like the explosion at Buncefield are exceptionally rare. However, society rightly demands the highest of standards from the high hazard industries.

"Businesses in this sector must manage the risks they create effectively because when things go wrong, the consequences are severe and can destroy lives and shatter local communities.

"Major hazard industries must learn the lessons of events like this. From the board room down companies must ask themselves these questions: do we understand what could go wrong; do we know what our systems are to prevent this happening; and are we getting the right information to assure us they are working effectively."

Howard Davidson, Thames director at the Environment Agency, added: "As a result of a successful investigation and prosecution, five companies have today been held to account for their failures.

"The Buncefield blast shattered the local community and left a long-term legacy of pollution. It has already involved a five-year clean up operation and the Environment Agency will be a presence around the site for many years to come."

## GENERAL FOODS BANBURY DUST EXPLOSION 18/11/1981

As well as choking the lungs and irritating the eyes dust can cause fires by becoming ignited. General foods used a pneumatically driven conveyor system to move corn starch used in the production of custard powder, the powder was transferred from a hopper to various feed bins. An accumulation of corn starch on the operating cylinder of the system cause a diverter valve to malfunction.

When a hopper was full the divert valve would divert the powder to the next one. On this occasions the valve did not work, thus the already over filled hopper continued to be filled. The dust spilled out into the surrounding area. The explosion did not occur in the custard processing area but elsewhere in the plant where the dust cloud was ignited possibly from an arc from a piece of electric switch gear. In 1981 at General Foods, Banbury, a dust explosion occurred when pneumatically conveying cornstarch for custard making, a hopper was overfilled. This created a dust cloud which was ignited by nearby electrical equipment, leaving nine men badly burnt and blowing out brick work and windows on all four walls. A flash fire also occurred which caused the severe nature of the burns. Nine people were seriously injured.

Sequence of event

- Failure of plant led to build up of starch powder
- Malfunction conveyor
- Feed bin overfilled
- Control system did not detect failure kept trying to fill bin
- No explosion relief
- Inadequate procedures & maintenance
- Ignited and Exploded
- Injuring nine

## KINGS CROSS FIRE 1987

The final death toll was 31 - the highest in an Underground accident since a train crash at Moorgate in 1975 killed 43 people. The last victim to be named was Alexander Fallon, who had been living rough in London. His body was not officially identified until January 2004.

Investigators said the most probable cause of the fire was a discarded match. Smoking on Underground trains had been banned in July 1984. After a fire at Oxford Circus station the ban was extended to all subsurface stations but smokers often lit cigarettes on the escalators on their way out. The escalator connected the Piccadilly line - one of five underground train routes which run through King's Cross - with the mainline station. The fire started as the evening rush hour was trailing off but hundreds of commuters were still in the station which is London's busiest. Many passengers were trapped underground as the escalator went up in flames. More than 150 firefighters wearing breathing apparatus tackled the blaze and searched for survivors.

The fire started on a wooden escalator and flashed, with searing heat and thick smoke, through the ticket hall. The escalators carried passengers to the heart of the blaze, and death.

The escalator on which the fire started had been built just before World War II. The steps and sides of the escalator were partly made of wood, which meant that they burned quickly and easily. Although smoking was banned on the subsurface sections of the London Underground in February 1985 (a consequence of the Oxford Circus fire), the fire was most probably caused by a traveller discarding a burning match, which fell down the side of the escalator onto the running track (Fennell 1988, p. 111). The running track had not been cleaned since the escalator was constructed in the 1940s and was covered in grease and fibrous detritus.

Other possible causes such as arson and an IRA bomb were quickly rejected by police as possible causes of the fire because of the lack of damage to the metal sides of the escalator that would have been present in the event of a bomb, or of significant traces of an accelerant as would be expected in an arson.

One survivor described how trains disembarked passengers onto smoke filled platforms: "A thing, I suppose a person, came stumbling down the stairs, his hair was all burnt off, his head was smoking and his skin blistering. He held his hands in front of him and there was smoke coming off them." Surgeons at University College Hospital said the injuries included some of the worst flash burns they had ever seen. "I think the fact that we have only seven patients is a reflection of the severity of the incident. So few survived to reach hospital," said a doctor.

London Regional Transport (LRT) strongly denied that its recently privatised cleaning methods are inadequate, allowing flammable fluff, which became soaked in machine oil, to accumulate under the escalator. Staff cuts and inadequate training have also been blamed. It emerged today that no sprinkler system was in operation at King's Cross and that LRT ignored recommendations made in 1984 to install one. Paul Channon, the Transport Secretary has announced a public enquiry into the disaster.

The first call received by the fire brigade was to

The Kings Cross fire was a devastating underground fire in London on November 18, 1987 which killed thirty-one people. It burnt out the top level (entrances and ticket halls) of King's

Cross St. Pancras London Underground station, a huge interchange station which has platforms on the Victoria, Piccadilly, Northern, Circle, Hammersmith & City, and Metropolitan lines.

The fire was caused by rubbish and grease beneath wooden escalators being ignited, probably by a discarded match. Although smoking was banned on the London Underground in February 1985 (a consequence of the Oxford Circus fire), smokers often lit up on their way out of the system. The fire started on the escalator, then flashed over and filled the ticket hall with flames and smoke. The investigation indicated that a couple of independent fires must have started previously due to same causes. They might have extinguished spontaneously.

The lack of visible flames and relatively clean wood smoke produced lulled the emergency services into a false sense of security, especially as firemen had attended more than 400 similar tube fires over the previous three decades. Firemen later described the fire as around the size and intensity of a campfire. Many people in the ticket hall believed that the fire was small and thus not an immediate hazard: indeed, an evacuation route from the tunnels below was arranged through a parallel escalator tunnel to the ticket hall above the burning escalator. Station staff claimed that the station below the fire did not need to be evacuated because of a belief that "fires rarely burn downwards", saying that there was no fire damage below the starting point of the fire. On the other hand, another consideration is ventilation; a fire being above does not mean that smoke and other products of incomplete combustion, including carbon monoxide, will not spread downwards. Alterations to normal ventilation flows are particularly common in underground environments, including underground railways.

The fire started beneath the escalator, spread above it, then flashed over and filled the ticket hall with flames and dense smoke. Investigations later showed that a particular combination of draughts, caused by an eastbound train arriving at the station while a westbound train was leaving, created a 12 mph wind through the station and up the escalator (known as the piston effect; this helps ventilate the tube), adding to the speed of the fire spreading. This wind was however found to be not enough to account for the flashover or the fire's intense ferocity, which was described as similar to a blowtorch.

The large number of casualties in the fire was an indirect consequence of a combustion phenomenon known as the trench effect. This effect meant that in the early stages of the fire the flames lay down in the escalator rather than burning vertically, so that they heated the steps higher up. In these early stages of the fire, the flames visible to anyone not standing on the burning escalator were a small part of the full story. The majority of the flames were lying down in the escalator trench; only a few protruded above the balustrade and were visible to observers. The lack of visible flames and relatively clean wood smoke produced lulled the emergency services into a false sense of security. Many people in the ticket hall believed that the fire was small and thus not an immediate hazard: indeed, an evacuation route from the tunnels below was arranged through a parallel escalator tunnel to the ticket hall above the burning escalator.

However, once a large enough number of steps had been heated, a flashover occurred on the escalator. When the treads of the escalator flashed over, the size of the fire increased exponentially and a sustained jet of flame was discharged from the escalator tunnel into the ticket hall, setting combustibles in the hall alight. The nature of the smoke changed from clean and thin to black and oily. The 31 casualties were those unable to escape from the ticket hall before succumbing to the effects of the latter type of smoke and the intense heat.

While inspecting an undamaged escalator, forensic investigators found charred wood in 18 places beneath the up escalator, which showed that similar fires had started before but had

burnt themselves out without spreading. All these combustion points were on the right hand side, which is where standing passengers are most likely to light a cigarette: passengers stand on the right to let walking passengers pass on the left. Smoking on Underground trains was banned in July 1984. Following a fire at Oxford Circus station the ban was extended to all subsurface stations but smokers often ignored this and lit cigarettes on the escalators on their way out. The investigators found a large build-up of grease under the tracks, but it was believed it would be difficult to ignite and slow to burn once it started; however it was noted that the grease was heavily impregnated with paper fragments from discarded tickets, sweet wrappers, fluff from clothing, and both human and rat hair; records showed the under stair tracks had not been cleaned since the escalator was constructed in the 1940s.

A test was conducted where lit matches were dropped on the escalator to see if this could have been the cause. Matches dropped did ignite the contaminated grease and the fire began spreading, this fire was allowed to burn for seven minutes before being extinguished. This test replicated the initial eyewitness reports up to that point but did not provide evidence as to why the fire flashed over.

The investigators next enlisted the UK Atomic Energy's research establishment at Harwell to make a computer simulation of King's Cross St. Pancras station. In the early stages of the modelled fire the flames lay down along the floor of the escalator rather than burning vertically and produced a jet of flame into the ticket hall. While the end result matched the tube fire exactly, the simulation's depiction of the fire burning parallel to the 30° slope of the escalator was thought by some to be impossible and it was suspected that the simulation might be inaccurate.

The next step was a scale replica of the escalator, built with the same materials, which was constructed at the UK's Health and Safety Executive site at Buxton in England. The fire was lit and after seven and a half minutes of normal burning the flames lay down as in the computer simulation. The metal sides of the escalator also served to contain the flames and direct the temperature ahead of the fire. Sensors indicated that wooden treads for 20 feet in front of the flames quickly reached between 500°C and 600°C. When the treads of the escalator flashed over, the size of the fire increased exponentially and a sustained jet of flame was discharged from the escalator tunnel into the model ticket hall.

The arrangement of the underground hall and escalators functioned all too effectively as an incinerator due to heat driven convection added to the usual ventilation system, with temperatures reaching 600°C: a BBC television news report called King's Cross St. Pancras station "an efficient furnace". The 30° angle of the escalators was discovered to be crucial to the incident and the large number of casualties in the fire was an indirect consequence of a fluid flow phenomenon that was later named the trench effect; this phenomenon was completely unknown prior to the fire.

The fire was exacerbated by a solvent-based paint used on the ceiling above the escalator, which ignited during the flashover, causing the composition of the smoke to change from light and thin to black and oily.

The Fennell Investigation into the fire prompted the introduction of the Fire Precautions (Sub-surface Railway Stations) Regulations 1989 (usually referred to as the *Section 12 Regulations* because they were introduced under section 12 of the 1971 Fire Precautions Act). These led to: the replacement of all wooden escalators on the Underground; the mandatory installation of automatic sprinklers and heat detectors in escalators; mandatory fire safety training for all station staff twice a year; and improvements in emergency services liaison.

One of the 31 victims of the fire remained unidentified until January 2004, when forensic evidence proved that he was 72-year-old Alexander Fallon of Falkirk, Scotland.

The ticket hall and platforms for the subsurface lines were undamaged and reopened the morning after the fire; the Victoria Line, its escalators only slightly damaged, resumed normal operation on the following Tuesday. The ticket hall for the three deep tube lines was reopened in stages over a period of four weeks.

The three escalators for the Piccadilly Line had to be completely replaced. The new ones were commissioned on 27 February 1989, more than 16 months after the fire. Until that time, the only access to the Piccadilly Line was indirect, either via the Victoria Line station or via what was for many years called King's Cross Thameslink and is now the Pentonville Road entrance, and sometimes at peak hours was possible in one direction only.

Access to the Northern Line platforms was already indirect, its escalators connecting only to the Piccadilly Line. As the traffic from all three deep tube lines would have overcrowded the Victoria Line escalators, Northern Line service to the station was completely suspended, the trains running through without stopping, until repairs were complete. The opportunity was taken to replace the nearly life-expired Northern Line escalators as well, which took a few days longer; the Northern Line station reopened, completing the return of King's Cross St. Pancras to normal operation, on 5 March 1989.

After the King's Cross fire, wooden escalators were phased out. In 1991 a report found only eight of the 26 safety recommendations made after the inquiry had been implemented fully. To the outrage of victims' relatives, nobody was ever prosecuted - the Director of Public Prosecutions and the Railway Inspectorate decided there was no justification for charges.

## PIPER ALPHA

In July 1988 the fire Piper Alpha platform, 120 miles northeast of Aberdeen resulted in the world's worst offshore oil disaster, claiming 167 lives. On investigation it was established that Occidental was not a company with a good health and safety record. The company had already had one serious near miss in 1984 when a mass evacuation of its platform had to be undertaken, the lessons were not learnt and as such over 150 men lost their lives.

Lord Cullen, who headed the inquiry into the incident, stated that the company had failed to learn from its mistakes, there were 'significant flaws in Occidental's management of safety' and that 'senior management were too easily satisfied' and 'relied on the absence of any feedback of problems as indicating that all was well'.

The facts indicated that, in the case of Piper Alpha, it was not just individual workers who were at fault but the whole culture of the organisation which put profits before safety. The company clearly had some responsibilities but, in the past, prosecuting an organisation has not been proven to bring about a cultural change.

The Piper Alpha platform was a large, fixed structure platform located about 120 miles north east of Aberdeen in 474 ft of water (see map below). Its function was to collect oil and gas coming up the risers, and to separate those streams into oil, condensate and gas. Piper Alpha contributed about 10% of the oil production from the U.K. sector of the North Sea.

At 10:00 p.m. on July 6$^{th}$ 1988 a massive explosion and subsequent fire led to the destruction of the platform. 167 men died (62 escaped). Because the accident occurred in the evening, many of the persons on board were off duty and were located in the living quarters. The smoke from the fire trapped these persons, who accounted for most of the fatalities.

Piper Alpha was a hub or collection platform - not only did it receive oil and gas from its own risers, two other platforms - Claymore and Tartan 'A' - fed gas to it. Piper Alpha then exported the combined gas streams to MCP-01. (It also used some of the gas for its own generators and as lift gas.) Its oil was pumped to the Flotta Terminal.

### *The Event*

The sequence of events leading up to the explosion and fire is complex; it is described in detail in Appendix 19 of *Lees' Loss Prevention in the Process Industries.* An overview of the event is provided below. The platform had two hydrocarbon condensate pumps: 'A' and 'B'. The 'A' pump was down in order that three maintenance tasks could be carried out on it. One of these tasks was to test and calibrate the pump's relief valve. This meant that the relief valve had been removed and two blind flanges put on the pump casing. The flanges were not bolted down tightly. The pump's gas operated suction and discharge block valves had been closed, but the pump was not blinded off. During the course of the day the maintenance activities were changed, and one of the jobs was closed out. At shift change information as to the status of the open work orders was not communicated properly.

At 9:50 p.m. the 'B' pump tripped out and could not be restarted. If neither of the two condensate pumps could be started within 30 minutes then the platform would have to be shut down - an expensive decision, so the decision was made to de-isolate pump 'A' and to bring it into service. However, the maintenance work on it had not been completed, nor had the permits to work been properly closed out. In particular, the relief valve blind flanges had not been tightened up.

Shortly after the 'A' pump was started condensate leaked from the loose flanges and an explosion occurred. It caused extensive damage and was followed by an oil pool fire and a blowdown of gas inventories to flare. The oil fire created a massive smoke plume that made the escape routes from the living quarters (where most of the personnel were located) impassable.

About twenty minutes after the initial explosion the Tartan gas riser failed and a second massive explosion occurred, followed by an escalation of the fire. Fifty minutes later the riser from MCP-01 also failed, resulting in a third explosion. A continued series of explosions and fires led to the destruction of the platform.

The inventory of oil and gas such as Piper Alpha is quite low. Therefore, even though the initial explosion and fire were large they should not have resulted in the total loss of the platform. There are two important reasons for the severe escalation of the event.

First, the Tartan and Claymore platforms continued to feed oil and gas to Piper, in spite of the fact that they could see that Piper was on fire. They did not stop the oil and gas flow because the communications systems had been destroyed in the explosion and “no one told them to stop”. They lacked the initiative to take unilateral action. Had they done so, it is virtually certain that this section of this book would need to have been written.

The second reason for the severe escalation of the event was that the condensate pumps were not protected by a blast wall. Piper had originally been built in 1976 as an oil platform. It was later converted to handle gas also. The original structure had only fire walls. With the addition of gas and condensate systems these should have been replaced with blast walls, but they were not. Hence the initial explosion was not contained. Moreover, since the mangers on the platform were killed in the initial blast there was never an effective emergency evacuation of those still on board.

Escape options were severely restricted. The helideck was unusable, and many of the escape routes to the lifeboats could not be used.

### *Long-term Consequences*

Just as the Santa Barbara blowout led to profound changes in environmental regulations in the United States, so Piper Alpha provided the impetus for many structural changes in the way in which safety was managed offshore.

The circumstances and causes of the disaster were examined in great detail by an inquiry led by Lord Cullen, a Scottish High Court judge. The report, *The Public Inquiry into the Piper Alpha Disaster* (Cullen 1990), which was highly critical of many of the design and operating practices that were in use at that time. The report led to a much stronger emphasis on the use of safety cases in the U.K. sector of the North Sea. Indeed, although safety cases had been prepared for North Sea offshore facilities prior to the Piper Alpha event, it is reasonable to state that it was the Cullen report that jump started the use of safety cases in offshore waters. More broadly, the Cullen Report became a major contributor to the development of process safety management systems - both onshore and offshore.

### *Risk Management Lessons*

#### Conversion of the Platform

The platform had originally been designed to handle primarily gas, and was later converted to handle oil and gas.

### Decision to Stop Work

The Tartan and Claymore platforms continued to pump oil and gas to Piper for a considerable period of time after the fire had started. The breakdown in command and control meant that no one told them to stop, so they decided not to stop pumping, even though they could see that Piper was on fire.

### Lockout / Tagout System

If two or more jobs are being carried out on the same piece of equipment or in the same area the chance for confusion as to which permit applies to which controls arises. Failure to control multiple permits was a major factor in the Piper Alpha incident - two permits were open on one compressor. When the first job was finished, its permit was closed and the compressor was started, even though the machine had a missing blind flange associated with the second job.

Workers probably relied too much on informal communications at critical times, such as shift turnover.

### Adherence to Permit-to-Work System

This was a system of paperwork designed to promote communication between all parties affected by any maintenance procedure done on the platform. The system on Piper Alpha had become too relaxed. Employees relied on too many informal communications and communication between shift changes was lacking. If the system had been implemented properly, the initial gas leak never would have occurred.

### Quality of Safety Management

The Cullen report was highly critical of the management system in the company. Managers had minimal qualifications, which led to poor practices and ineffective audits.

### Disabling of Protective Equipment by Explosion

The firewalls on Piper Alpha could have stopped the spread of a fire. They were, however, not built to withstand an explosion. The initial blast blew the firewalls down, and the subsequent fire spread unimpeded.

### Safety Training

The workers on the platform were not adequately trained in emergency procedures, and management was not trained to make up the gap and provide good leadership during a crisis situation.

### Auditing

Occidental Petroleum had regular safety audits of its facilities but they were not performed well. Few, if any, problems were ever brought up, even though there were serious issues with corrosion of deluge system pipes and heads and many other issues. When a major problem was found, it was sometimes just ignored.

### Temporary Safe Refuge (TSR)

TSR on each installation should have a breathable atmosphere through prevention of smoke ingress and provision of fire protection; escape routes and embarkation points should be determined through safety cases.

Prevention of smoke ingress into TSR is available through smoke and gas detectors that initiate smoke dampers and prevent circulation of smoke throughout the TSR.

**Evacuation and Escape**

More than one route to helicopters and lifeboats must be present at any given time to ensure evacuation of the platform in a crisis situation. To facilitate escape from a hazardous situation, luminescent strips and heat shielding provide visibility in smoke and protection from flames, respectively. Secondary escapes such as ropes, ladders, and nets are also available as backup for the more sophisticated escape methods.

Occidental escaped prosecution because the authorities concluded that there was insufficient evidence for a case of corporate manslaughter. A private criminal prosecution by victims' families, similarly, could not be pursued on cost grounds.

In 1996 the Law Commission proposed a new crime of 'Corporate Killing' which would allow for the prosecution of the senior management of negligent companies. Prosecution would follow where a death has been caused 'by a failure in the way in which the corporation's activities are managed or organised, to ensure the health and safety of persons employed in, or affected, by those activities'.

To avoid the evasion of liability, such as occurred after the collapse of the Herald of Free Enterprise trial, the Law Commission recommended that 'it should be possible for a management failure on the part of a corporation to be a cause of a person's death even if the immediate cause is the act or omission of an individual'. Perhaps unsurprisingly, these proposals have found little support either in government or the senior ranks of the judiciary. Companies have been held to account for health and safety offences since 1833 but over the last few years there has been greater public interest in ensuring that senior managers are held to account for the actions of their organizations.

INQUIRY Cullen Report

CAUSES Most Likely: Ignition of flammable gas build up resulting from leak from condensate injection pump.

Pump had been shut down (day shift) to remove a safety pressure valve for recertification. Blind flange assembly fitted in its place. On the nightshift a second pump was restarted. Condensate entered the relief line and gas escaped from the non-airtight flange assembly. Initial blast put out main power supplies – emergency systems failed.

**WINDSOR CASTLE FIRE - 20th November 1992**

The castle suffered severe damage in a fire, which destroyed some of the most historic parts of the building. Over the next few years the castle was fully repaired at great expense. The question of how the funds required should be found raised important issues about the financing of the monarchy, and led to Buckingham Palace being opened to the public for the first time to help to pay for the restoration.

Just before midday, television news programmes were suddenly putting up news flashes, saying that the 900 year old Windsor Castle was on fire. Before long, images of Windsor Castle well alight was accompanying these news flashes.

A fire had began at 11.33am in the Queens Private Chapel, when the radiated heat from a 1000 watt halogen spotlight left too close to curtains by a painter, set on fire. The fire set off an alarm in the watchroom of the castles own fire brigade. The Castle had 20 of its own firefighters, six of which were full time. They were equipped with a Land Rover and pump tender, and were based in the Royal Mews, which was to the south of the castle.

The location of the fire was shown on a map of the castle and indicated by an illuminated indicator light. Immediately the Chief Officer (Mr. Smith) of the castles fire brigade sounded the public fire alarm, and then paged the other firemen who were routinely patrolling the castles ground, and informed them of the incident. At 11.37 he then telephoned the Royal Berkshire Fire and Rescue Service via a direct line informing them of a fire alarm actuating.

The fire was shown initially to be in the Brunswick Tower, but soon many other indicator bulbs lit up, as the fire spread to neighbouring rooms, including the State Apartments. Once he had informed all the necessary persons, he made his way to the Brunswick Tower where he found a serious fire in progress. He initiated immediate salvage operations to put into action by members of staff from the castle.

Prince Andrew, who was at the castle, was one of those who assisted removing these valuable items. These salvage operations had been planned previously due to the priceless works of art and furniture kept within the castle. Thanks to these early operations, very few of these items were damaged during the fire.

Within 7 – 8 minutes of the call, (by 11.45am) the first of the appliances from the Royal Berkshire Fire and Rescue Service had arrived. Within another 4 minutes 10 pumping appliances were in attendance, and the fire was now blazing out of control.

More appliances were ordered to the castle, and 20 were in attendance by 12.12pm, followed by a total of 35 pumping appliances and 2 hydraulic platforms being in attendance at 12.20pm. There were now 225 firefighters on the scene. Due to the large number of appliances and firefighters needed, they were called in from London, Buckinghamshire, Surrey, Oxfordshire, and Berkshire.

The officer in charge on the fireground of this historic fire was Deputy Chief Officer David Harper, who reported directly to Chief Officer Garth Scotford who based himself at the Royal Berkshire Fire Control rooms in Reading. The spread of the fire was rapid, and by 12.20pm the fire had spread to the largest of the State Apartments, St. Georges Hall, and was getting worse.

It was decided that one way to help stop the spread of the fire, was by using tradesmen to erect firebreaks. These were erected at the southern wall of the Green Drawing Room (at the end of St George’s Hall on the east side of the Quadrangle), and at the north west corner at Chester Tower, where that tower joins the Grand Corridor. The time was now 1.30pm. By

this time, firefighters had started to gain the upper hand on the fire, but the roof of the State Apartments was now showing signs of collapse.

At 3.30pm, with the fire now surrounded the floors in the Brunswick Tower collapsed. This collapse was accompanied by large volumes of smoke. This smoke caused confusion for a short time as firefighters were thought to be lost within the fires area, but they were soon located.

At 4.15pm, as night fell, flames in the Brunswick Tower flared up once more, and by 6.30pm, the flames, now well over 50 feet above the tower could be seen illuminating the night sky for miles around. Images of this were seen worldwide as 24 hour news programmes followed the incident.

The roof of the Brunswick Tower finally gave up its fight against the flames at 7.00pm, as the flames broke through into the night sky, accompanied by a spectacular shower of sparks rising high into the night. This was followed soon after by the collapse of the roof over St. Georges Hall

Nine hours after the start of the fire it was brought under control, but it was to take another three hours to extinguish it. Firefighters would continue to damp down small pockets of fire well into the next day, and 8 appliances would remain at the scene for many more days.

Firefighters used over one million gallons (4,500 tons) of water fighting the fire. This was taken from Castle mains and from the River Thames. Nine principal rooms and over 100 other rooms over an area of 9,000 square metres were damaged or destroyed by the fire. This was approximately one fifth of the castles area.

The day following the fire, the Queen visited the castle to personally thank many of those who had tirelessly worked to prevent this tragedy being far worse.

The restoration of Windsor Castle began immediately following the devastating fire, it took 5 years and cost £37,000,000

The Queen dubbed 1992 her “Annus Horribilis” after the Windsor Castle fire

***The progress of the fire***

The fire began in The Queen's Private Chapel at 11:33 am when a spotlight ignited a curtain. The alarm went off in the watch-room of the Castle fire brigade, manned by Chief Fire Office Marshall Smith. The site of the fire was shown by a light on a large grid map of the whole castle. Initially the Brunswick Tower alone was indicated, but lights soon lit up indicating that the fire had quickly spread to several neighbouring rooms. The major part of the State Apartments was soon ablaze.

Patrolling firemen were paged by an automatic system, and at 11:37 am Mr Smith pressed the switch to alert the Control Room at Reading. He then activated the public fire alarm, known as an ER7 alert (a continuous high pitch tone), and telephoned the Royal Berkshire Fire and Rescue Service on a direct line.

Mr Smith proceeded to the Brunswick Tower to assess the situation, and to begin the salvage operations which, together with fire precautions, had been the main responsibility of the castle brigade since the county force took over responsibility for fire-fighting at Windsor Castle in September 1991.

The Castle still had its own 20 strong force, of whom six were full-time. Equipped with a Land Rover and pump tender, they were based in the Royal Mews, stables south of the castle.

The first appliances of the Royal Berkshire Fire and Rescue Service arrived at the castle between 11:44 am and 11:45 am, some 7–8 minutes after the alert was given. By 11:48 am 10 pumping appliances had been ordered to the fire and the principal officer on duty within the brigade the Deputy Chief Officer David Harper had been informed.

By 12:12 pm there were 20 engines, and by 12:20 pm there were 35, with over 200 firemen from London, Buckinghamshire, Surrey, and Oxfordshire, as well as from Berkshire.

The Fire Incident Commander was David Harper, Deputy Chief Fire and Rescue Officer of the Royal Berkshire Fire and Rescue Service. The Chief Officer Garth Scotford was out of the country, on holiday.

By 12:20 pm the fire had spread to St George's Hall, the largest of the State Apartments, and further reinforcements were called. The fire-fighting forces by then totalled 39 appliances (including two hydraulic platforms) and 225 fire-fighters. As an indication of the scale of the fire, there had been only one 30-appliance fire in the whole of Greater London since 1973.

By 1:30 pm firebreaks had been erected by tradesmen at the southern wall of the Green Drawing Room (at the end of St George's Hall on the east side of the Quadrangle), and at the north-west corner at Chester Tower, where that tower joins the Grand Corridor. The fire-fighters had by this time begun to bring the fire under control (though the roof of the State Apartments had begun to collapse).

At 3:30 pm the fire was surrounded, and the floors of the Brunswick Tower collapsed, concentrating the fire there. Firemen had to temporarily withdraw to locate three men who were briefly lost in the smoke, and on a second occasion withdrew when men were temporarily unaccounted for when a roof fell in.

At 4:15 pm the fire had revived in the Brunswick Tower. As night fell the fire was concentrated in the Brunswick Tower, which by 6:30 pm was engulfed in flames 50 feet (15 m) high, which could be seen for many miles. At 7 pm the fire broke through the roof of the tower, and later the roof of St George's Hall finally collapsed into the conflagration.

By 8 pm the fire was finally under control, having burnt for nine hours, although it continued to burn for a further three hours. By 11 pm however the main fire was extinguished, and by 2:30 am the last secondary fires were put out. Pockets of fire remained alive until early Saturday, some 15 hours later. Sixty firemen with eight appliances remained on duty for several more days.

The fire had spread rapidly due to lack of fire stopping in cavities and roof voids.[2]

Over one million gallons (4,500 cubic metres) of water from Castle mains and from the River Thames had been used in fighting the fire.

***Extent of damage to the Castle***

There had been no serious injuries, and no deaths. Dean Lansdale (aged 21), a decorator in the Private Chapel, was burnt while removing pictures (of which he had rescued three). He

was moved to the royal surgery then to hospital. Christopher Lloyd, the Surveyor of The Queen's Pictures, suffered a suspected heart attack, while five firemen were taken to hospital, two with hypothermia, three with minor burns and dust in their eyes.

The major loss was to the fabric of the Castle. The false roof above St George's Hall and the void beneath the floors for coal trucks had allowed the fire to spread. It burnt as far as the Chester Tower. Several ceilings collapsed. Apartments burnt included the Crimson Drawing Room (which was completely gutted), the Green Drawing Room (badly damaged, though only partially destroyed, by smoke and water), and The Queen's Private Chapel (including the double sided nineteenth century Henry Willis organ in the gallery between St George's Hall and Private Chapel, oak panelling, glass, and the altar).

St George's Hall partially survived, with the wall largely intact, but with the ceiling collapsed. The State Dining Room (in the Prince of Wales Tower; which was badly damaged, as was the fabric of the tower), and the Grand Reception Room (80% severely damaged, though 20% of the ceiling was eventually saved) were also devastated.

Smaller apartments damaged or destroyed (and over 100 rooms were involved in the fire) included the Star Chamber, Octagon Room, Brunswick Tower, Cornwall Tower, Prince of Wales Tower (badly damaged), Chester Tower (badly damaged), Holbein Room, and the Great Kitchen (which lost its plaster cove, and most of its mediæval timber).

The external wall above the bay window of the Crimson Drawing Room (between the Prince of Wales and Chester Towers) was seriously calcified.

The Waterloo Chamber was undamaged, as were the Grand Vestibule, Rubens Room, Ante-Throne Room, Throne Room, Ball Room, Serving Room, and China Closet (which was not affected although it was surrounded by the fire). Overall some 80% of the area of the staterooms was undamaged.

Fortuitously the seven most seriously damaged rooms had largely been emptied the previous day for rewiring. The Castle had just completed an 18-month phase of rewiring in most of the rooms destroyed.

Items from the Royal Collection lost included the Sir William Beechey equestrian portrait George III at a Review, which was too large to remove from its frame; a large late 1820s sideboard by Morel and Seddon (18 feet long); several pieces of porcelain; several chandeliers; as well as the Willis organ; and the 1851 Great Exhibition Axminster carpet partly burnt.

It took 250 firefighters 15 hours and 1.5 million gallons of water to put the blaze out.

One hundred rooms were damaged in the fire, which is thought to have been started by a spotlight shining on a curtain. An intense public debate was sparked about whether the taxpayer should foot the repair bill, as the castle is owned by the British Government and not the Royal Family. The Queen agreed to meet 70% of the costs, and opened Buckingham Palace to the public to generate extra funds. The £40m restoration took five years and was completed in November 1997.