Schweizerischer Feuerwehrverband

December 11, 2005

Buncefield Fire

Quick Look Report

bürkel baumann schuler

Swiss Fire Brigade Association

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A major fire occurred on 11th December 2005 in a storage tank depot 40 km north-west of London. After being triggered by a powerful explosion, numerous tanks in which heating fuels and engine fuels were stored burned for several days. The fire is being described as the largest fire incident in Europe since the Second World War. The present assessment of information relating to the major fire in the Buncefield storage tank depot was produced shortly after the incident. It is based on enquiries addressed to specialists and an examination of official information and press reports. Because of the uniqueness of the event and the copious visual image and press material, a briefly worded and quickly available assessment of this information is of great interest to the emergency services.

The present *Quick Look Report* contains selected photographs and graphics. The visual information is supplemented by a description of the incident with comments and interpretations together with quotations from the press.

Winterthur, 30th December 2005

Bürkel Baumann Schuler
Engineers + Planners AG
Gertrudstrasse 17
CH-8400 Winterthur
Switzerland
Tel.: +41 52 260 07 10
Fax: +41 52 260 07 20
Mail admin@bbs-ing.ch

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Abbreviations

BP	British Petroleum
BPA	British Pipeline Agency
FBU	Fire Brigades Union
GMT	Greenwich Mean Time
HFB	Hertfordshire Fire Brigade
HPA	Health Protection Agency
HSE	Health & Safety Executive
HOSL	Hertfordshire Oil Storage Ltd.
J8/9	Junction 8/9
M1	Motorway 1
NHS	National Health Service
UK	United Kingdom
UKOP	UK Oil Pipeline Network
UKPIA	UK Petroleum Industry Association

Conversions

Length

1 yd = 3 ft	= 0.9144 m
1 mile = 1760 yd	= 1,609.3 km

Volume

1 UK gal	= 4.5461 dm^3
1 US gal	= 3.7854 dm^3

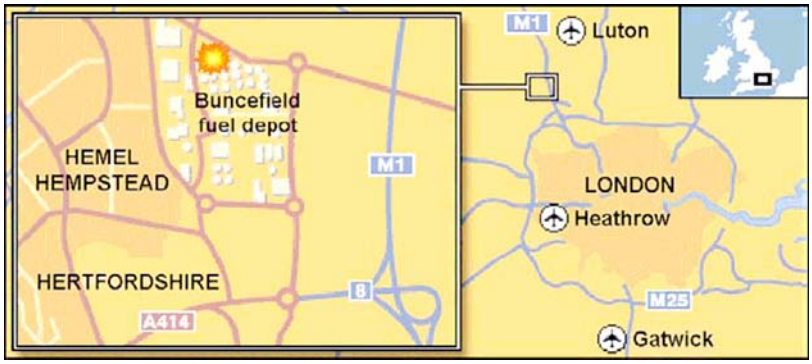
Pressure

1 psi	= 6.895 kPa
	= 0.06895 bar

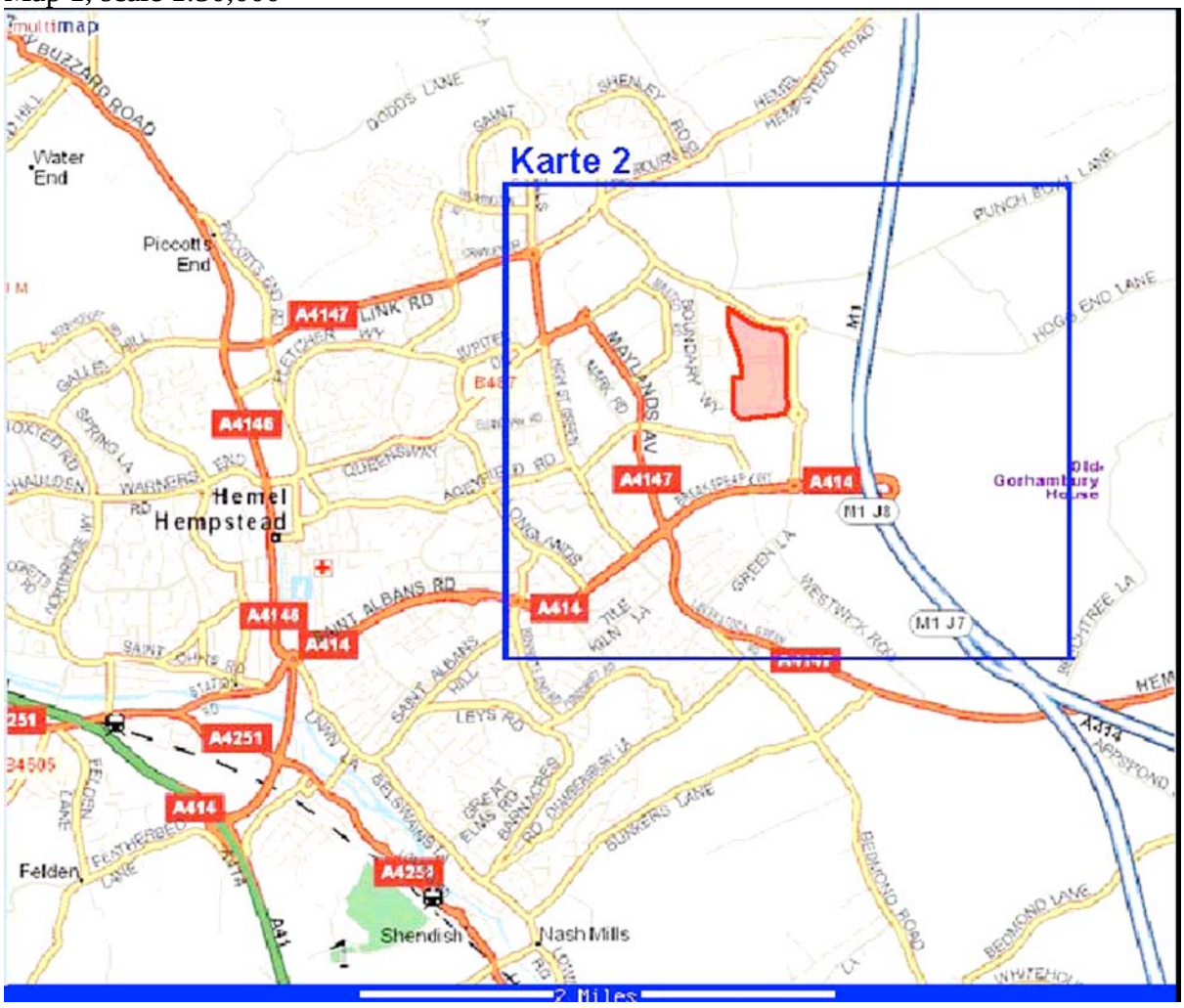
1 Site of the incident

1.1 Overview

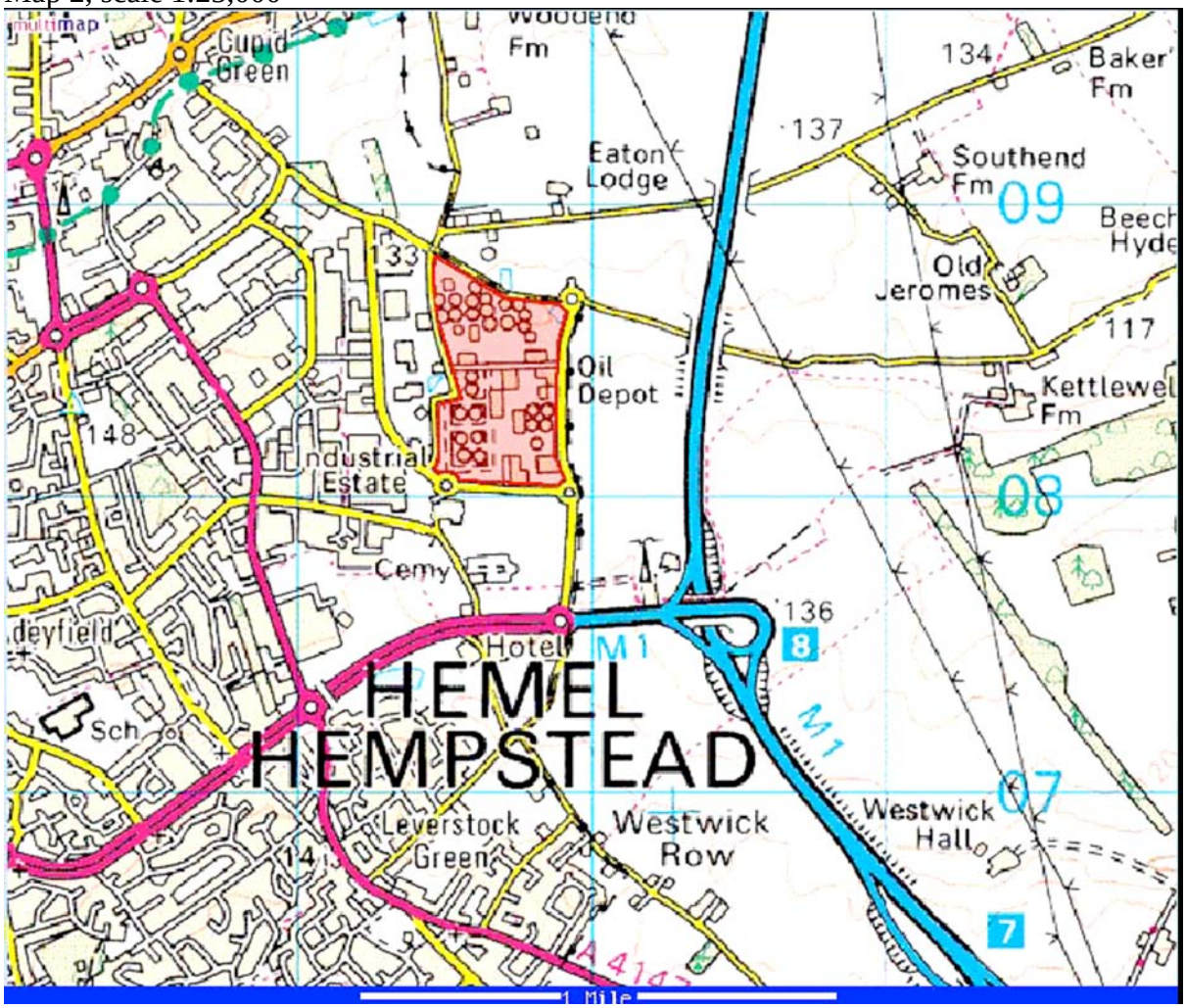
The Hertfordshire Oil Storage Ltd. (HOSL) storage tank depot is situated in the County of Hertfordshire approximately 40 km northwest of London. The fuel depot, known locally as Buncefield Depot, is located between London and Luton Airport. It is situated in an industrial estate on the eastern edge of the town of Hemel Hempstead at Junction J8 of the M1 motorway running northwards from London.



Map 1, scale 1:50,000



Map 2, scale 1:25,000

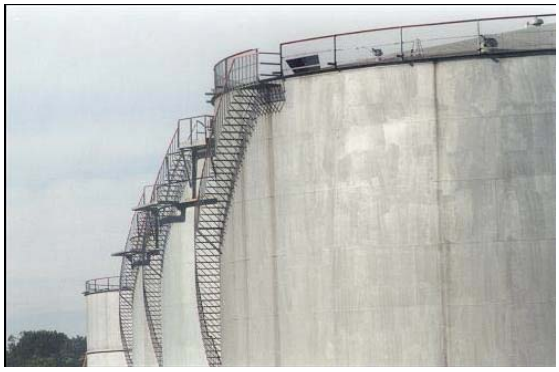


Aerial photograph

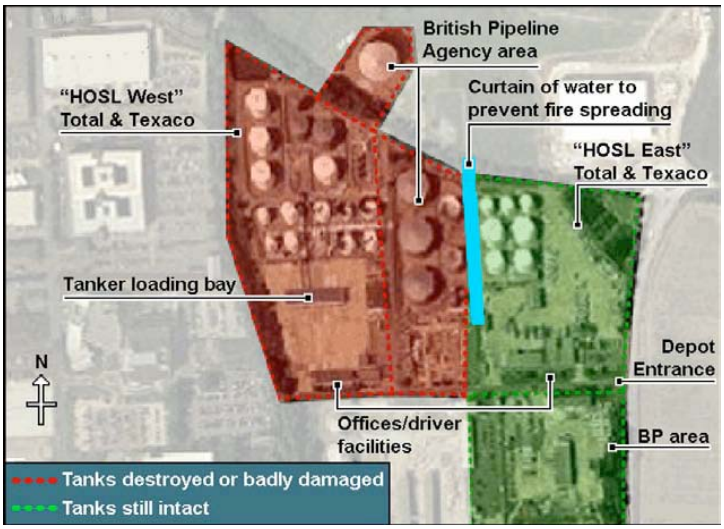
1.2 The storage tank depot

The HOSL storage tank depot has a capacity of approx. 270 million litres of fuel, corresponding to about 5% of the entire quantity stored in Great Britain. The annual turnover of fuels in the storage depot is approx. 2.4 million metric tons. This involves mainly petrol, diesel and kerosene. The fuel storage depot, which was opened in 1968, belongs to the petroleum companies *Total* (60%) and *Texaco* (40%). Parts of the installation are operated by *BP* and the *British Pipeline Agency*.

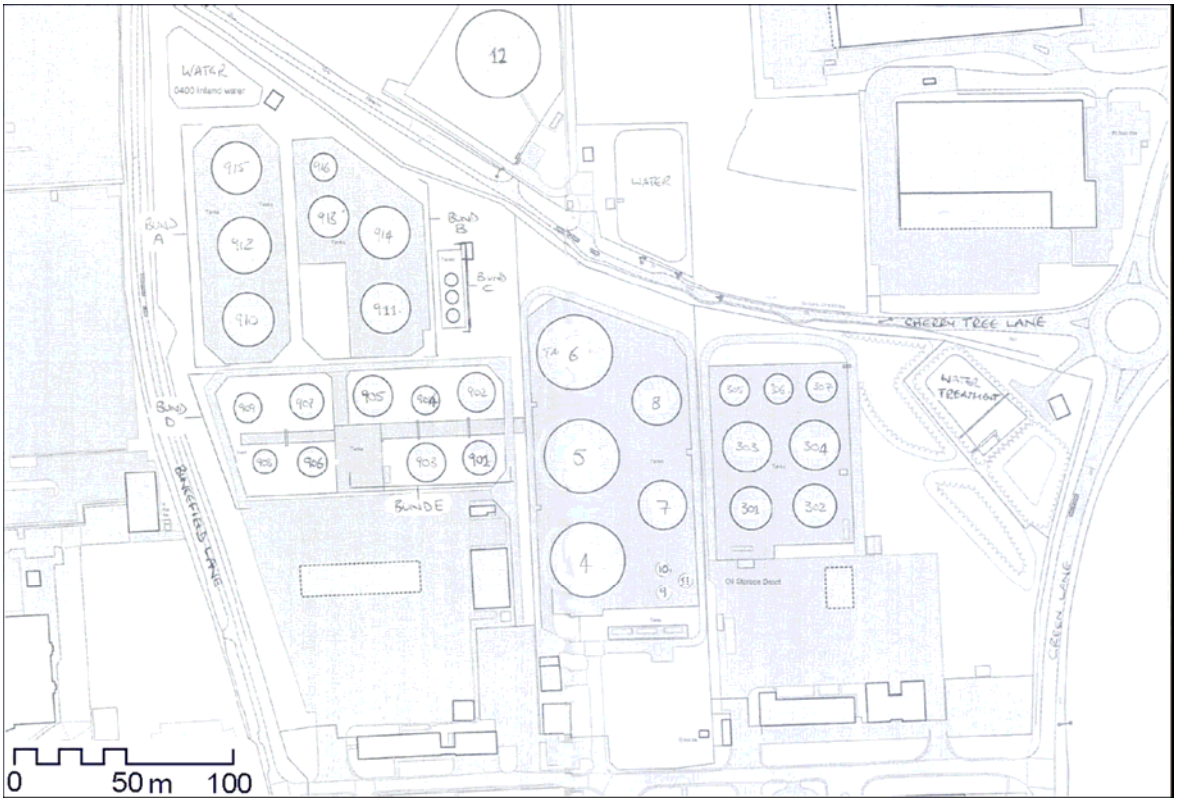
The installation is an important element (hub) of the British Pipeline Network (UKOP). It is supplied through a pipeline. Buncefield is very important for the supply to Heathrow, Gatwick and Luton airports, because half of the installation is used for kerosene. Heathrow is supplied directly via a pipeline. In addition, 400 tanker vehicles per day are loaded.



As a result of the fire incident, the northwest part of the installation with a total of 22 fuel tanks was destroyed or severely damaged. The size of the affected area is approx. 300 x 400 m and comprises an area of about 80,000 m^2.



The diagram above shows that the eastern part of the tank installation, "HOSL East", was protected from the heat effect of the fires by a water curtain. However, an assessment of the visual image material shows that the *British Pipeline Agency (BPA)* tanks, which can be recognised in pale green colour in the above aerial photograph, were also not all involved in the fire. The seven white tanks in the "HOSL East" area, in which kerosene was stored, were not affected by the fire incident. Furthermore, the hosepipes that can be seen in the aerial photograph on the following page permit the conclusion that the deployment of extinguishing efforts took place primarily at *BPA* Tanks 4, 5 and 6. A plan with the tanks and their numbers can be found on the next page.



Aerial photograph from the east, with the hosepipes at the entrance to the storage tank depot in the foreground. The seven intact white tanks ("HOSL East") and the pale green *British Pipeline Agency* tanks behind them and partly affected by the fire are easily recognisable. Of the two Tanks 7 and 8 with floating roofs, Tank 8 (right) has burnt out. The content and thus the danger emanating from Tank 7 were for a long time unknown.

2 Explosion and fire incident

2.1 The incident

The first and largest of the total of three explosions occurred on the morning of Sunday, 11th December 2005 at 06:03 hrs. Two further explosions occurred just less than half an hour later, at 06:27 and 06:28. The explosions were violent and were still audible even at a large distance (100 km). A more detailed description of the consequences of the explosions can be found in Section 3.3. Subsequently there were intense fuel fires, which the Fire Brigade was not able to bring under control until some days later.

2.2 Fire Brigade deployment

2.2.1 Sequence of events

Sunday, 11.12.05

06:03 First explosion with damage to fuel tanks, damage to buildings and consequential fires

06:27 Two further explosions

24:00 Delay of the planned deployment of extinguishing operations (use of extinguishing foam) because of the possible environmental damage to surface waterways and groundwater

Monday, 12.12.05

08:00 Start of deployment with
- Installation of protective equipment
- Operations with extinguishing foam
- Transport of water from a lake about 1.6 km away. Six high-pressure pumps with a capacity of 32,000 litres/min. are in use.

12:00 Half of the original 20 fires have been extinguished.

15:00 Further tanks have been extinguished.
Because of a leak, fuel escaped from Tank 5, which had already been extinguished and which consequently ignited. The Fire Brigade then withdrew. There was danger to the intact Tank 7 situated alongside Tank 5. In particular, the nature of the fuel stored in Tank 7 was unknown. Because of the explosion hazard, the M1 motorway remained closed and the evacuation zone around the fuel storage depot was enlarged. Unmanned appliances remained in use to extinguish and cool the tanks.

20:00 Resumption of extinguishing operations by the Fire Brigade.
It is expected that it will be possible to extinguish all the burning tanks during the night.

Tuesday, 13.12.05

06:00 Destruction of another storage tank leads to a renewed withdrawal by the Fire Brigade.

08:30 Extinguishing operations are resumed.

12:00 All fires have been extinguished except for the largest Tank 12, which is still burning. The smoke plume is smaller and its colour has become paler because of the evaporated extinguishing water.

16:45 It is reported that all storage tank fires have been extinguished.
Several smaller seats of fire still exist. However, these are not extinguished to reduce the danger of explosion.

Wednesday, 14.12.05

06:00 Another fire has broken out. However, this is also not extinguished to reduce the danger of explosion.

Thursday, 15.12.05

Numerous small fires occur on pools of fuel.

Friday, 16.12.05

12:00 All fires have been extinguished. However, the danger of renewed ignitions remains, especially since the wind has become stronger and as a result the foam carpet may break open.
The Fire Brigade is deployed with seven extinguishing appliances and is continually renewing the foam carpet.

2.2.2 Extinguishing operations

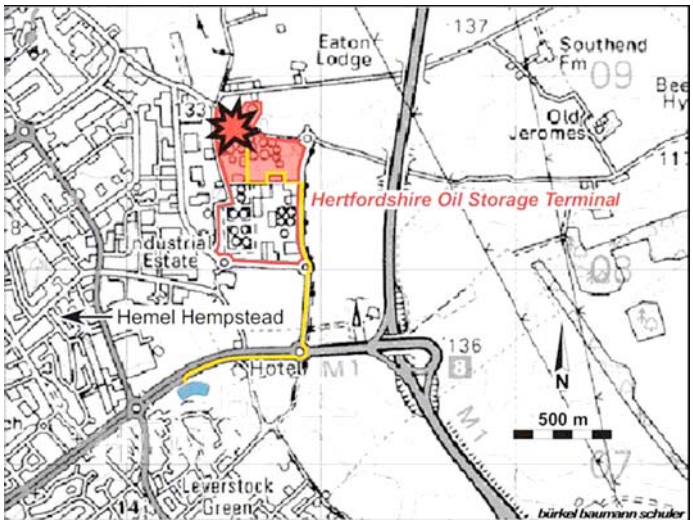
It is said that the Fire Brigade management initially doubted whether extinguishing foam would have any effect at all in view of the vigour of the fire. However, the success of the fire-fighting operation showed that the extinguishing efforts were ultimately successful. However, an assessment of the efficiency of the deployment is still awaited. The opearation required 250,000 litres of foam concentrate. It must be assumed that this quantity was not available on site. The question remains open as to whether the delay in deployment was also a result of, among other things, the procurement of foam concentrate. At any rate, it was possible to procure the necessary amount within 24 hours. Numerous hosepipes were laid to a lake at a distance of 1.6 km to transport the water. The hoses can be seen on various photographs. The water was conveyed by six powerful (high-capacity) pumps.

In spite of the intense heating effect, the Fire Brigade deployment took place very close to the flame front. Very small distances are mentioned in this connection. The danger to the Fire Brigade personnel arose primarily from the considerable probability of unexpected explosions. This danger also resulted in the temporary withdrawals by the Fire Brigade. Unmanned extinguishing appliances were employed during the periods of withdrawal.

A situation that caused increased difficulty was the fact that the Fire Brigade lacked information about the materials stored in some individual tanks. After all the tank fires had been extinguished, further fires – presumably pool fires – were no longer extinguished, with a view to preventing explosions. A total of 650 Fire Brigade officers from 15 brigades took part in the fire-fighting. No-one was injured during the fire-fighting deployment.

Hosepipes to transport extinguishing water, together with emergency services vehicles at a roundabout at Junction J8 of the M1 motorway at a distance of 1.2 km from the site of the fire.

Hosepipes at the entrance to the HOSL Storage Tank Depot on the east side of the installation, and the layout of the hoses within the site.



Excerpt from a map showing the route of the hosepipes to transport extinguishing water from a lake 1.6 km away.

Fire-extinguishing vehicle with foam monitor in use

The situation on Monday, 12th December. The large Tank 12 (left) is fully alight but is not being extinguished. The burnt-out Tanks 913, 914, 915 (at far right at the edge of the photo) and 916 can be recognised. Smaller fires are also visible at numerous points in the foam blanket alongside the tanks.

Fire-extinguishing vehicle with foam monitor on the road between Tanks 915 and 912 (in the foreground) and 916 and 913 (from left to right). The tanks are burnt out except for a small seat of fire on the roof of Tank 912. The foam carpet on the ground largely prevents the outbreak of fires. However, the small seats of fire along the bund wall are interesting.

2.3 Precautionary measures to protect waterways

It is obvious that the precautions to protect a nearby river and the groundwater were a central problem in the preparations for the fire-extinguishing operation. According to the photographic material, containment bunds to retain escaping fuel and extinguishing water were present. Therefore it can be assumed that there was no immediate danger to a receiving waterway or the groundwater.

2.4 The cause of the incident

Experts express the opinion that the explosion that started the fire was caused by the ignition of a fuel-air mixture. In view of the enormous effect of the explosion, a large amount of highly volatile flammable liquid must have been released. Because of its low flashpoint, this can only have involved petrol (gasoline) that had evaporated and formed an explosive gas cloud by mixing with the oxygen of the atmosphere. It is hoped that it will be possible to find out the starting point of the release based on recordings from the surveillance cameras. Safety experts suspect that a leak on a tank or fuel pipeline, or a release as a consequence of a technical breakdown was the cause. The almost windless weather and the low temperature close to the ground may have led to conditions that favoured the formation of a large gas cloud above the pool of fuel.

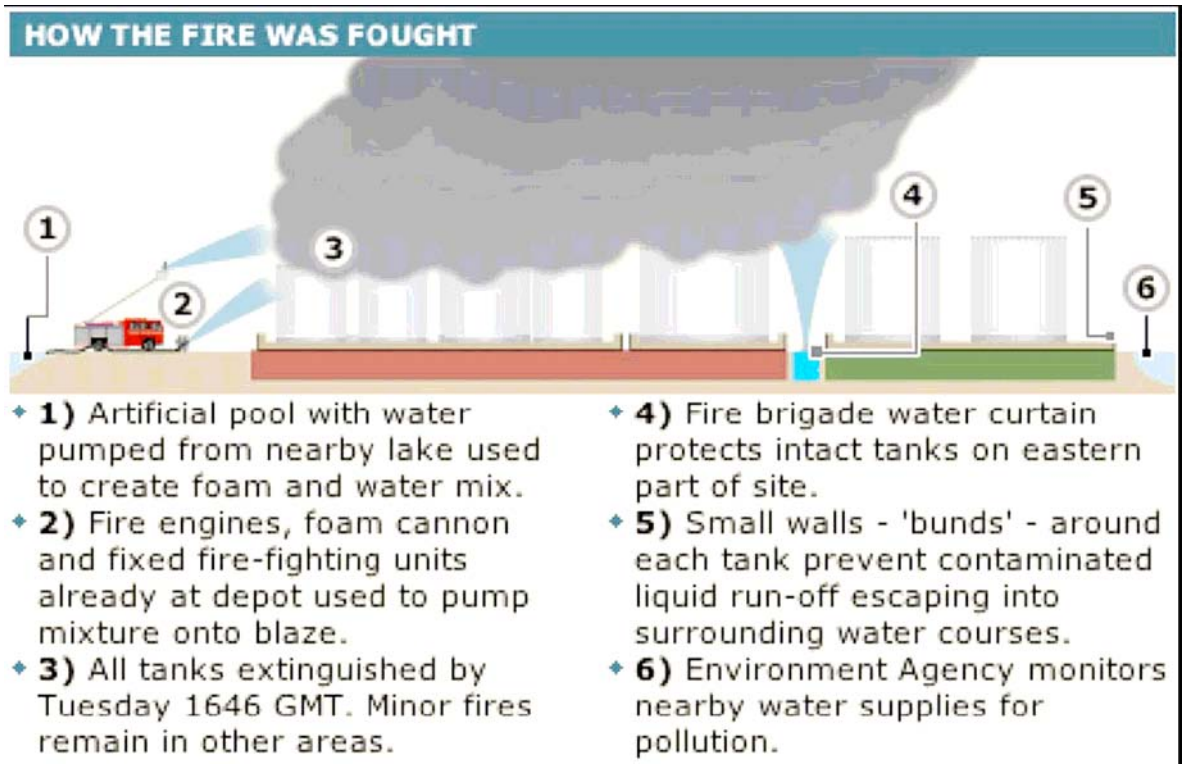
The thesis of the explosion of a large gas cloud is supported by the statement by a watchman who at the moment of the explosion was present in the second storey of the *Fujifilm* Company's building about 300 metres away. The night-watchman had detected the odour of fuel inside and outside the building during his inspection one hour beforehand.

If the incident was triggered by a petrol vapour explosion, a large quantity of fuel of the order of several thousand litres must have been released, and a very large cloud of ignitable petrol vapour with a diameter in the order of magnitude of 200 metres must have been able to form. Experts assess a leak of this kind as extraordinary. Moreover, gas clouds generally do not explode when ignited, but burn rapidly ("Flash Fire"). The pressure wave generated by the combustion during a deflagration of this kind is generally weak. However, the effects of the atmospheric shockwave described in Section 3.3.2 were massive. Since a very large gas cloud is required for the flame front during the combustion of the cloud to be accelerated so greatly as to result in such pressure effects, it is suspected that the incident was triggered by the ignition of an exceptionally large cloud of petrol vapour.

2.5 Assessment of the Fire Brigade operation

The fire was obviously started by violent explosions. At the same time, however, the question as to what damage the explosions caused to the fuel storage facility is unclear. The question of where exactly the fire incident began and how it developed in the first few minutes is equally unclear. Therefore it is also difficult to judge whether a rapid deployment by the Fire Brigade could have prevented the major fire. The fact that the fire-fighting operation was delayed by more than 24 hours after the start of the fire was criticized by the press.

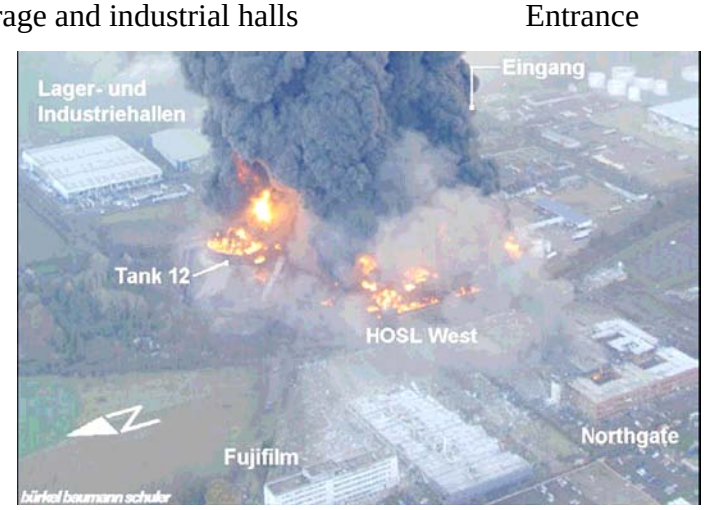
The British Fire Brigades Union (*Fire Brigade Union, FBU*) criticized the local Fire Brigade organisation (*Hertfordshire Fire Brigade, HFB*) in the sense that it was said to be inadequately prepared for a major incident. The Fire Brigade rejected these criticisms and explained that monthly exercises had been carried out in the storage tank depot – the last of them three weeks before the incident. However, based on initial information, there are grounds for suspecting that the exercises assumed a fire affecting one storage tank and not an unlikely MCA (Maximum Conceivable Accident). Therefore the operational documentation was probably not aimed at either a violent explosion or several tanks catching fire. The fact that it was not possible to provide the Fire Brigade with any information about the materials stored in the individual tanks is most astonishing.



3 The consequences of the incident

3.1 Overview

A few buildings in the vicinity of the fuel storage depot were severely damaged by the explosions and the effects of the subsequent fire. Based on the pattern of damage to the tank installations and surrounding buildings, it can be assumed that the explosions took place in the area with Tanks 913, 914 and 916. The head office of the IT company *Northgate Information Solutions*, which was closest to these tank installations, and the industrial hall situated alongside it were totally destroyed. The *Fujifilm* building together with two storage and industrial halls located to the east were also severely damaged.



3.2 Personal injuries

The incident and in particular the explosion did not claim any fatalities. Only 49 injured persons – three of them severely injured – were recorded. A tanker vehicle driver was taken by surprise at the loading station in the open air at a distance of about 200 m. He was knocked over by the atmospheric blast wave and suffered a perforated eardrum as a result of the overpressure. The night-watchman in the *Fujifilm* building about 300 m away was in the second storey inside the building. He was also knocked over as a result and suffered lacerations caused by debris.

It must be assumed that if the time of the incident had been during working hours, at least several dozen people in the open air and in the neighbouring buildings would have been struck by debris and would have been killed. In addition, a larger number of people would also have suffered hearing damage in addition to severe injuries.

3.3 Effects of explosion and fire

3.3.1 Thermal effects

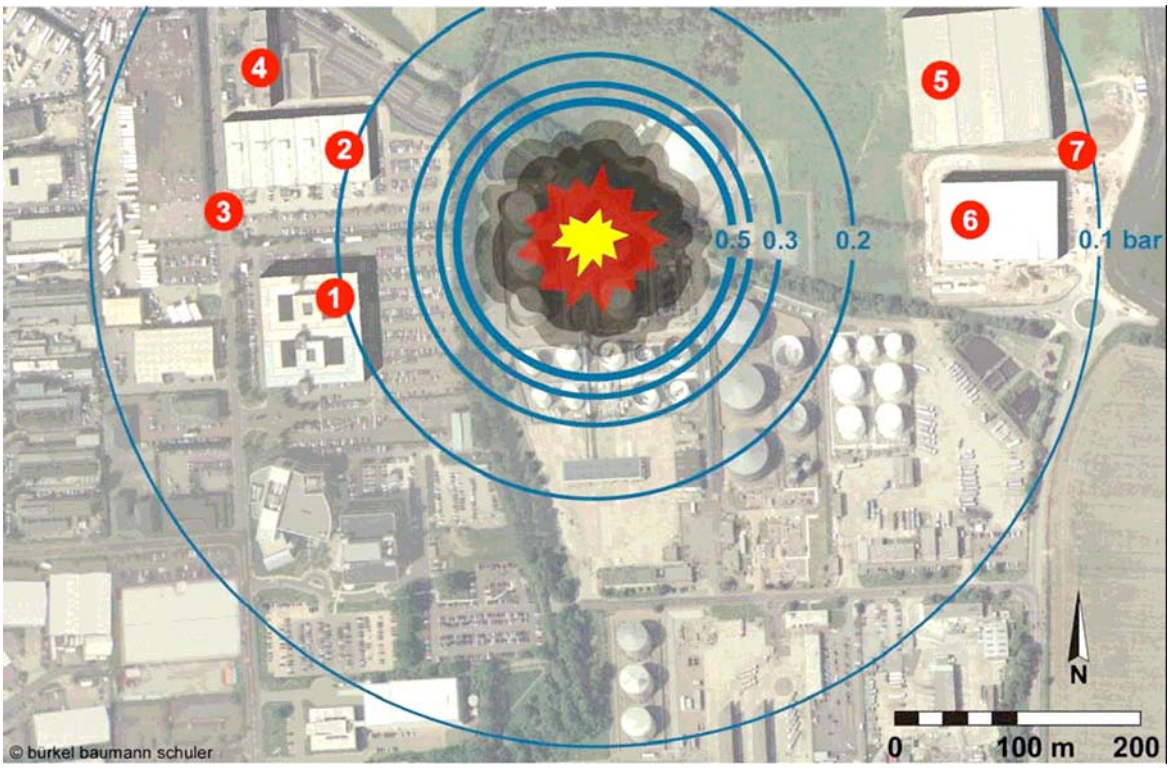
From eyewitness reports and from the photographic material it can be concluded that the thermal effects of the explosion fireball and the heat radiation from the subsequent fire were immense. Eyewitnesses report flames one hundred metres high. The burnt-out vegetation that surrounded the storage tank site to the north and west at a distance of about 40 m also permits conclusions to be drawn regarding intense thermal effects.

As a consequence of the thermal effects of the explosion and subsequent fires, a part of the *Northgate Information Solutions* office building at a distance of about 150 m also caught fire. The building fire is recognisable by the white smoke plume in the right-hand photograph below. Flames are also visible in the inner courtyard of the building in the left photo below.

3.3.2 Air blast effects

The atmospheric blast wave caused by the explosion resulted in major damage to the surrounding buildings. Minor damage to buildings still occurred even at a greater distance. For example doors forced in and broken windowpanes were reported at a radius of 800 metres. In one case tiles were lifted from a roof. Occasionally glass windows were broken even at a distance of more than one kilometre. However, statements by politicians that 60 important commercial buildings and business premises had suffered structural damage so severe that they would have to be demolished must be judged to be exaggerated.

Conclusions can be drawn about the propagation of the overpressure wave based on the damage to the surrounding above-ground buildings/structures and the reported effects of the pressure at a greater distance, together with the eardrum injury to the tanker vehicle driver about 200 m away. This is illustrated in the diagram below. An atmospheric blast wave of this intensity is the result of an explosion with a TNT equivalent of about 15,000 kg.



It is apparent from the illustration that the peak overpressure of the incident atmospheric blast wave was probably slightly more than 0.2 bar at the *Northgate* building (1) and at the West Hall (2). The overpressure was probably about 0.15 bar at the *Fujifilm* building (4) and the two storage halls to the east (5) and (6). The magnitude of the peak overpressure was still about 0.05 bar at a distance of 800 m.

In each case, the overpressure peak of the reflected atmospheric blast wave, which is the definitive factor for the effect of pressure on buildings, is approximately twice as large as the peak overpressure of the incident atmospheric blast wave shown above. However, the position of the building relative to the incident atmospheric blast wave is also a definitive factor with regard to the reflection.

The following illustrations show building damage at the various locations identified by numbers. The estimated overpressure peaks of the reflected atmospheric blast wave are also stated.

(1) Northgate

The peak overpressure of the reflected atmospheric blast wave was probably approx. 0.5 bar. The building is generally severely damaged. The window glazings have been shattered on the entire building (including on the rear side of the building). Façade claddings have been torn away. However, the load-bearing security (probably a steel-reinforced concrete supporting structure) is likely to be still guaranteed. It is difficult to judge which damage has resulted from the atmospheric blast wave and which from the following building fire.

Aerial photograph of the head office of the *Northgate Information Solutions* Company

East façade of the *Northgate Information Solutions* building

(2) West Hall

For the south-eastern corner of the "West Hall" building, the peak overpressure of the reflected atmospheric blast wave is estimated to be 0.5 bar. The hall was completely destroyed by the blast wave. Large sections of the supporting structure of the hall have been destroyed and the roof of the most severely affected part of the building has caved in. Because of the generally light-weight construction method, the sheet metal claddings of the outer walls and the roof have been torn away by the atmospheric blast wave.

Aerial photograph of the "West Hall"

Photo looking south

Photo looking northwest
(*Fujifilm* building in the background)

(3) West Entrance

The maximum overpressure of the reflected atmospheric blast wave at the entrance to the industrial estate on the west side probably still amounted to about 0.3 bar. The completely destroyed “West Hall” is recognisable in the photos below.

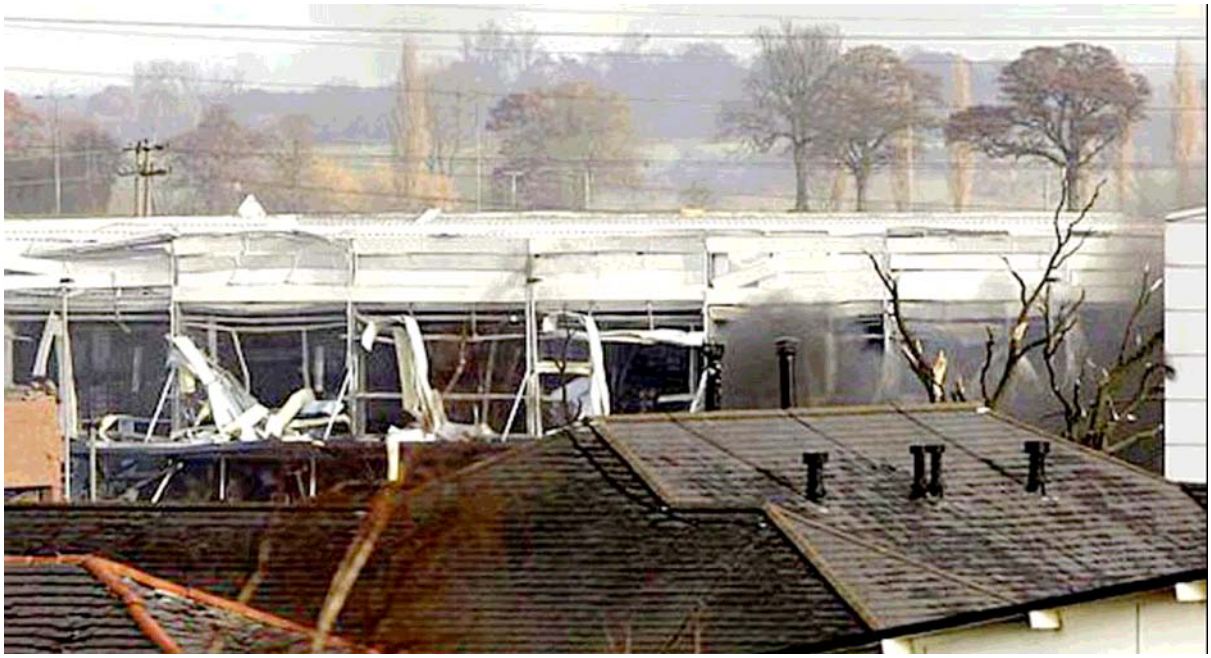
(4) Fujifilm

A reflected overpressure of 0.3 to maximum 0.4 bar probably acted on the east façade of the *Fujifilm* building. The building was seriously damaged at the corner of the building situated nearest to the explosion, façade claddings and roof superstructures being torn away. The glass windows were destroyed throughout the entire building.

(5) (6) East Halls

The two industrial and storage halls lie to the east at a distance of approx. 250 m from the presumed site of the explosion. The atmospheric shockwave reflected vertically at the west façades of the halls had an estimated peak overpressure of 0.3 – 0.4 bar. This shockwave destroyed the claddings of the hall buildings along the entire length of the facades.

Hall (5) at the left and Hall (6) at the right, with the burning Tank 12 in the foreground



Metal façade destroyed along the whole length of Hall (5)

(7) East Entrance

An incident air shockwave that still had a maximum overpressure of about 0.1 bar was the decisive factor at the entrance between the two “East Halls” at a distance of about 350 m. Because of the position of the building facades, reflections of the atmospheric shockwave were scarcely a decisive factor at these positions. Due to the comparatively small pressure and based on the pattern of damage, it can be assumed that the damage to the facades visible in the following photos was caused by the overpressure inside the hall.

Façade elements forced outwards as a result of the overpressure in the interior of the Hall (5). The burning Tank 12 is recognisable in the background, about 250 metres away.

(8) Hemel Hempstead

The atmospheric shockwave caused by the explosion still caused glass windows to break in the town of Hemel Hempstead at a distance of one kilometre and more. The maximum overpressure of the reflected air shockwave at these locations was 0.05 bar or less.

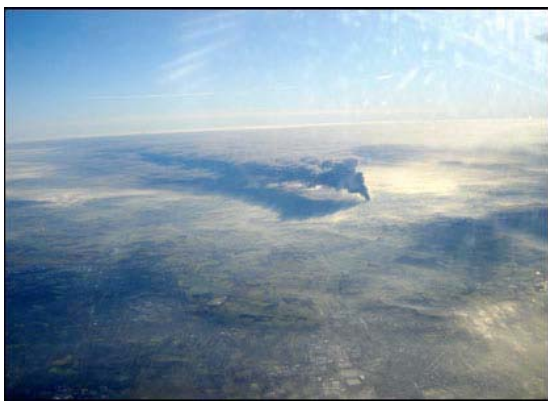
3.3.3 Smoke emission

The fire at Tank 12 emitted the most smoke. This involved the largest tank on the HOSL storage tank depot site. Its capacity can be estimated as about 20,000 m^3. Based on the photographs, it can be assumed that the Fire Brigade allowed the tank to burn out and did not extinguish it. A description of the smoke dispersal and the associated ecological and health aspects can be found in the following Section 3.4.

3.4 Smoke from the fire

3.4.1 Spread of smoke

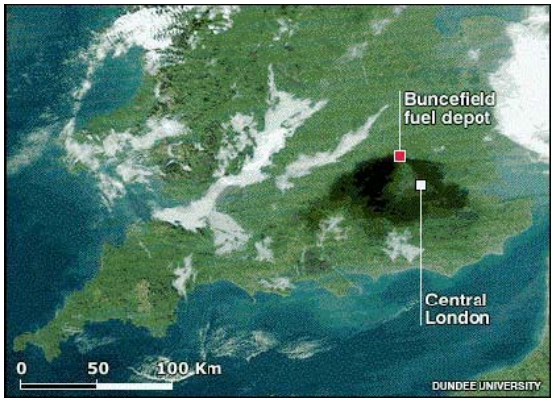
The information relating to the smoke plume from the storage tank depot fire is contradictory. However, it is obvious that the smoke rose vertically upwards above the fire. With regard to the smoke plum dropping down to the ground, the meteorological conditions during the fire were favourable. There was a temperature inversion with a layer of cold air near the ground. This promoted the ascent of the smoke into higher layers of the atmosphere. At a height of 2,000 – 3,000 metres the smoke plume drifted first of all to the south-west and then in a south-easterly direction. Thus the pollution was transported to/at a great height. No contamination of the ground was detected at any point.



These satellite images show how smoke from the Buncefield fuel depot fire spread after the initial explosions at 0600 GMT on 11 December. By lunchtime on 12 December, the smoke had reduced to a tiny black plume. (All images courtesy Dundee University except the first, which is from US NOAA.)

Smoke plume at a height of 2,000 – 3000 metres above the ground

Smoke plume over London



The smoke plume extended 100 km in an east-west direction and 50 km in a southerly direction.

3.4.2 Evacuations, cordoning off

A cordoned-off zone was set up at a distance of 800 metres (½ mile) around the storage tank depot. Although the smoke rose vertically upwards above the fire, 2000 people in the vicinity of the storage tank depot were evacuated. It was necessary for 500 people to be housed in emergency accommodation. In addition, about 70 schools within a radius of 17 kilometres were closed. It is conceivable that these arrangements made by the authorities were sensible for psychological reasons, since the population was not in a position to assess the danger.

The M1 motorway was closed until Monday evening between the two junctions J8 and J9 because of the risk of further explosions in the storage tank depot half a kilometre away.

3.4.3 Danger to health

An aircraft equipped with special instrumentation flew through the smoke plume and took air samples. The soot particles that were measured had a size in the region of 10 µm. Particles of this size are generally not very dangerous to health. Discussions arose subsequently as to the toxicity of the smoke. Attention was drawn to the fact that the smoke also contained smaller particles and was therefore said to be carcinogenic. A professor from Edinburgh University ascertained that the fires in Kuwait after the Iraq war emitted many times more soot without any effects on the health of the population being observed. The national agency responsible for monitoring air quality was not able to detect any effects of the fire at ground level.

4 Summary and Conclusions

4.1 Characteristic features of the incident

- In view of the very high cost of the damage, the incident is a Major Accident according to the Swiss Major Accidents Regulations.
- The starting point of the incident was the release of a large quantity of fuel that caused a powerful explosion with a considerable atmospheric shockwave (air blast wave).
- In view of the time of the explosion at about 6 a.m. on a Sunday morning, no-one was killed by the explosion.
- The explosion caused major damage to the fuel storage depot as well as to neighbouring buildings. The destruction created in the storage tank depot triggered further explosions shortly after the (first) explosion.
- The explosions triggered a major fire with the following consequences:
  - procuring fire-extinguishing water from a lake 1.6 km away, possibly not foreseen
  - procuring large amounts of fire-fighting foam concentrate
  - a rather marginal evacuation of people from the neighbourhood
  - the danger of explosions during the fire-fighting deployment of Fire Brigade officers.
- The fire resulted in a gigantic smoke plume. However, this did not drop back to the ground, and is not relevant in view of the combustion of substances of all kinds throughout the world.

4.2 Operational documentation and fire brigade deployment

Based on the available documentation, the supposition must be that the operational documents were not aimed at either an explosion with large potential energy or at a fire involving several tanks. The statements by the Fire Brigade Chief Officer who was responsible point towards the exercises being based on the assumption of a fire in one tank. The fact that the Fire Brigade did not possess any information about the materials stored in individual tanks is most astonishing. An aspect that must be judged favourably is the organisation of an information event for the residents in the close vicinity of the fuel storage depot, with participation by the authorities, the Police, the Fire Brigade and representatives of the storage tank depot operators from the *Total* Company.

Taking into consideration the fact that the operational planning did not cover very comprehensively an incident involving a fire in several fuel tanks, the resulting key points for operations management are as follows:

- Taking precautionary measures to protect a river and the groundwater
- Co-ordinating 15 brigades of the Fire Service with a total of 650 officers
- The construction of water transport hosepipes 1.6 km in length to a lake, and the use of numerous powerful high-capacity pumps
- Obtaining a large quantity of extinguishing foam concentrate
- Obtaining information about the materials stored in the individual tanks
- The safety of Fire Brigade personnel in view of explosions during operations in the front line

4.3 Crisis management

Because of the favourable progress of the incident, especially the small number of injured persons and the ideal weather conditions, the operations staff who were deployed did not need to take any difficult decisions or to make any important weighing of interests. The evacuations that were carried out and the advice to the population in connection with the smoke would not have been necessary. The same also holds true for the closure of schools within a large radius.

It can be concluded that no great demands were imposed on the other emergency service agencies, when compared to the Fire Brigade. According to the available information, the following tasks were mentioned.

- Evacuation of residents in the close vicinity of the fuel storage depot by the Police
- An assessment of the hazard to waterways as a result of fire-fighting foam, and advising the Fire Brigade on the planning of safety precautions
- The meteorological assessment of the smoke plume with regard to the possibility of it dropping back to the ground
- Taking samples of the smoke by a specially equipped aircraft
- The setting up of closures on the M1 motorway.