Title: Casualties resulting from flooding of industrial sites

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Abstract

Aim of this study was to get insight into the number of possible casualties that could be expected as a consequence of flooding of industrial sites.

First a literature study was carried out using a database containing more than 17000 industrial accidents. From the literature study it could be concluded that only high-energy floods (i.e. high flow velocities) (were reported to) cause calamities (like fire and explosions) with casualties. Floating of tanks was observed in certain cases, and in addition to (storage) tanks, pipelines were vulnerable objects. No effects of toxic substances released and subsequently dispersed as a result from floods are reported.

Secondly, a calculation of the expected number casualties was carried out for a simulated flooding event near the city of Krimpen aan de Lek in the Netherlands, using generally recognised principles and models applied during quantitative (safety) risk assessment studies (software programme EFFECTS version 5). Only one site, where sufficient amounts of dangerous substances were stored, was found to be located such that a significant release could be expected. This was a location where 86 tons of ammonia (NH₃) was present. Under unfavourable atmospheric conditions release of this volume could result in over 2000 deaths, and many more people needing medical attention. More realistic conditions, under which a dyke breach could be expected, could result in about 55 casualties. Although flood conditions might be such that a release could occur, local (safety) measures taken significantly reduce the probability of occurrence of such a scenario.
Executive summary

Every year, floods cause enormous damage all over the world. In the last decade of the 20th century floods accounted for about 12% of all deaths from natural disasters, claiming about 93,000 fatalities (source: OFD / CRED international disaster database). In the Netherlands, the hazard of large-scale floods leading to extensive damage and loss of life is always present, since large parts of the country lie below sea-level. In this sub-project, part of the Delft Cluster “consequences of floods” project, the matter of loss of life caused by floods is investigated. Since it appeared from a review of international literature that the knowledge on this subject is very limited, the problem is approached at various levels of detail. The aims of this subproject are twofold: generating knowledge of loss of life caused by floods by “learning” from the events during international floods, and, secondly, to improve the methods for estimation of loss of life caused by floods for the specific situation in the Netherlands.

In the first part of the study statistics on loss of life in worldwide floods are analysed. Also the occurrence of other, non-lethal health effects, is investigated. The second part proposes a framework for the estimation of loss of life caused by floods in the Netherlands. Finally, special attention is given in the third part to the possibility of additional fatalities resulting from the flooding of industrial sites. The main results of each of these three subprojects are summarized below

1. Loss of life caused by floods: an overview of mortality statistics for worldwide floods

Floods can have a substantial impact on public health, and indirectly lead to a decrease of socio-economic welfare. In this report the effects of worldwide floods on human well-being are studied. A review of international literature on flooding health effects and information from case studies was conducted. This investigation shows that injuries, illnesses, diseases and mental health effects can occur after flooding. Especially psychological effects can continue to last for months and even years after the flood and are therefore an important consequence.

The main part investigates loss of life statistics for different types of floods and different regions with general information from the OFDA / CRED international disaster database concerning a large number of worldwide flood events. Figures are presented on mortality for worldwide floods. The results show that the mortality associated with flood events strongly depends on the flood characteristics, such as the available time for evacuation and the rate of rising of the flood waters, i.e. on the flood type.

Also, causes of flood mortality have been studied with detailed information on flood fatalities for a limited number of cases. In general, it can be stated that the way people respond to the exposures is a critical factor in the morbidity and mortality associated with such events. Especially in European floods, the loss of life is to a large degree associated with risk-taking behaviour.

However, the insight in health effects of floods, both morbidity and mortality, is limited. This outlines the need for more and better quantitative data on health impacts associated with all categories of flooding. This includes centralized and systematic national reporting of deaths and injuries from floods using a standardized methodology.

2. Consequences of floods: the development of a method to estimate the loss of life

In this part a framework for the estimation of loss of life caused by floods in the Netherlands is proposed. The method takes into account the effect of evacuation during the flood and various mechanisms which lead to fatalities during a flood. The relationships between flood characteristics and number of fatalities are based on data from the 1953 disaster, during which the south-western part of the Netherlands was flooded, and that caused 1836 fatalities. The method is applied in two case studies to give a first estimate of the number of fatalities caused by a river dike breach near Rotterdam and failure of the coastal defence near Katwijk, both leading to a flood of the Central Holland area. The results indicate that, contrary to what is generally believed, river floods may cause more fatalities than coastal floods. This mainly depends on the topography and elevation of the flooded area and the period during
which inflow takes place. To further improve the method for estimation of loss of life, knowledge generated on drowning causes can be applied. Also the modeling of evacuation before and during the flood requires significant improvement.

3. Casualties resulting from flooding of industrial sites
Aim of this part of the study was to get insight into the number of possible casualties that could be expected as a consequence of flooding of industrial sites. First a literature study was carried out using a database containing more than 17000 industrial accidents. From the literature study it could be concluded that only high-energy floods (i.e. high flow velocities) (were reported to) cause calamities (like fire and explosions) with casualties. Floating of tanks was observed in certain cases, and in addition to (storage) tanks, pipelines were vulnerable objects. No effects of toxic substances released and subsequently dispersed as a result from floods are reported. Secondly, a calculation of the expected number casualties was carried out for a simulated flooding event near the city of Krimpen aan de Lek in the Netherlands, using generally recognised principles and models applied during quantitative (safety) risk assessment studies (software programme EFFECTS version 5). Only one site, where sufficient amounts of dangerous substances were stored, was found to be located such that a significant release could be expected. This was a location where 86 tons of ammonia (NH3) was present. Under unfavourable atmospheric conditions release of this volume could result in over 2000 deaths, and many more people needing medical attention. More realistic conditions, under which a dyke breach could be expected, could result in about 55 casualties. Although flood conditions might be such that a re-release could occur, local (safety) measures taken significantly reduce the probability of occurrence of such a scenario.

Concluding remarks
Finally, it can be stated that as a result of this subproject more knowledge is generated on the main factors influencing loss of life due to floods. The results of these studies provide some insights in the potential magnitude of flood events and can aid the development of vulnerability indicators for flood hazards. Insights gained can provide background for decision-making on the desired level of flood protection and the application of measures to prevent flood deaths. The research on loss of life caused by floods will be continued in an ongoing PhD study at Delft University.
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1 Introduction
As outlined in accompanying reports the consequences of flooding were assessed by modelling a rather severe dike breach near the city of Krimpen. This part of the study is concerned with the way floods affect industrial areas and possible casualties as a consequence of damage done to installations on such sites.
The study consists of 2 parts:
1) A literature search into industrial accidents related to flooding events
2) An assessment of the number of casualties that could be expected as a result of flooding of the industrial sites present in the modelled ‘Krimpen’ area.

2 Literature study – Casuistry of industrial accidents related to flooding
This literature study was done using the TNO database FACTS (2001). This database contains more than 17000 industrial accidents, covering a period of about 20 years. With the key word “flood*” all accidents were selected that were related to flooding events. Thirty hits were found. These are summarised in the appendix.
The following conclusions can be drawn from the reported accidents:
- Calamities only occurred in case of high-energy floods (i.e. high flow velocities),
- Floating of tanks was observed in certain cases. Although not specifically mentioned, relatively high water depths (providing sufficient upward force) are likely to be required.
- In addition to storage tanks, pipelines appear to be very vulnerable. Although this was not mentioned, it is likely that this is particularly the case for aboveground pipelines.
- Failure of storage tanks with flammable material frequently resulted in fire and/or explosions.
- No effects of toxic substances released and subsequently dispersed through the incoming water are reported.

3 Casualties resulting from flooding of industrial sites in the ‘Krimpen’ modelling area

3.1 Selection of locations, components and methods
The study concentrated on relatively large-scale effects (i.e. outside the site boundaries) resulting from partial or complete breakdown of installations containing flammable or toxic compounds. This would include large storage tanks of e.g. fuels and also components like chlorine and ammonia.
The volumes, locations and range of chemicals stockpiled in the ‘Krimpen’ modelling area were established using the so-called Dutch UBI-list. The UBI-list was compiled in 2001, on request of the Dutch Inter-provincial Council (IPo) and the Ministry of VROM (Environment and Spatial Planning). This list consists of industrial activities that are potentially polluting for soils. This list was particularly useful for the identification of fuel storage tanks. A total of 24 sites with large volumes of oil products were identified, as well as 89 petrol stations. Locations with large volumes of toxic compounds could be found through the register of so called ‘Seveso’ sites held at VROM. These are sites subject to the EU Seveso II Directive (1996), for which special safety measures are required as a result of the large volumes of dangerous compound used and/or stored. Eight such companies were identified.
The literature study showed that serious accidents could only be expected if high flow velocities exist. In addition high water levels could result in floating of (smaller) tanks. Modelling showed that high flow velocities (say in excess of 2 m/s) only occurred in a very small area near the breach (see Figure 1). Water heights that could be expected to result in floating of (smaller) storage tanks (say water heights of 1 m or more) are present in a much larger area (Figure 2). No vulnerable objects were found in the high-flow area. In the area covered with more than 1 m water many vulnerable sites were found. Therefore many fuel tanks may become damaged and release (some of) their contents. However, because of the relatively ‘gentle’ conditions under which the release takes place, the dominant...
effect will be environmental (water) pollution as a result of floating oil layers. No casualties are expected because of fire or explosions.

In the flooded area two ‘Seveso’ sites were identified with large volumes of toxic material, in this case ammonia. A brewery, with approximately 60 tons of NH₃, used for cooling purposes, and a fertiliser plant with 86 tons of ammonia. For the location of the brewery a maximum water height of 12 cm and a maximum velocity only slightly above 0 m/s were predicted by the model. The location of the fertiliser plant could be subject to water heights approaching 1 m and flow velocities of up to 1 m/s. Therefore, only the fertiliser plant can be considered a health risk for people present in the vicinity of the plant during the flood. Only for this facility potential casualties were calculated.

Companies subject to the “Seveso” directive need to carry out special safety studies, on the basis of which a major accident prevention policy should be written up. In case flooding is considered a potential risk it should be included in the study. It is not clear whether or not the fertiliser company indeed did consider flooding risks. However, for the purpose of this study the potential effects were calculated.

One of the scenario’s that should be considerer during a Quantitative Risk Analyses (QRA) (according to the Dutch implementation of the Seveso Directive - CPR-18E (1999)) is damage to a tank resulting in a release of the full contents in a 10 min period. One could envisage such damage as a result of a puncture of the tank by sharp objects that may be floating on the floodwater, or by rupture of a pipe. This was considered the worst-case scenario, and used in the calculations. Much of the ammonia released from the tank will disperse through the atmosphere and may cause serious health problems when inhaled by people. Calculations shown below were carried out with TNOs software package EFFECTS (2003). This package uses the algorithms and methodology officially recommended for QRAs by the Dutch Commission for the Prevention of Disasters (CPR).
3.2 Results of effect calculations

3.2.1 Release and dispersion
A release of 86 tons ammonia in 10 minutes is equivalent to a flux of 143 kg/sec. About 10-20% of the, initially liquid, NH$_3$ will directly be released into the atmosphere as a result of the so-called ‘adiabatic flash’. Another part of the released NH$_3$ will dissolve in the floodwater. Heat generated during the dissolution process will cause some additional evaporation of NH$_3$. Experimental results (Raj et al., 1974) have shown that in total 58% will dissolve in the floodwater and 42% will end up in the atmosphere and disperse. Only the fraction dispersed through the atmosphere is expected to cause adverse health effects. Ammonia dissolved in the excess floodwater will not cause any serious health problems.

Ammonia concentrations in the atmosphere can be calculated in two ways:
- **Point source**, in which it is assumed that all evaporated material directly originates from the point of release. That would result in a source term of $(0.42 \times 143 =) 60$ kg/sec.
- **Surface source**, in which it is assumed that evaporation, resulting from the generated heat during dissolution, takes place from the area of the water body in which the product dissolves. This results in the following:
  - **Amount NH$_3$ evaporated**: $(0.42 \times 86,000) \sim 36,000$ kg.
  - **Amount NH$_3$ dissolved**: $(0.58 \times 86,000) \sim 50,000$ kg.
  - **Solubility of ammonia in water equals 0.52 kg NH$_3$ / liter H$_2$O. Assuming a maximum concentration of 10% of the solubility this leads to 52 kg/m$^3$. To dissolve 50 ton ammonia approximately 960 m$^3$ of water will be required, which, at a water depth of 88 cm, would result in a surface area of the water body of 1100 m$^2$, or a circular pool of water with a diameter of ca.37 meter.
  - **This would result in a source strength of (36000 kg / (600 s x 1100 m$^2$)) \sim 0.055$ kg/m$^3$.s.
3.2.2 Health criteria
The following health criteria were used:
- Concentrations leading to 50% (human) lethality upon exposure during 10 min: 10 400 mg/m³ (LC-50 (10 min))
- Concentrations leading to 1% (human) lethality upon exposure during 10 min: 3240 mg/m³ (LC-01 (10 min))
- Concentrations causing irritation of respiratory system: 70 mg/m³ (AGW)
- Concentrations causing slight nasal irritation: 14 mg/m³ (VGW)

3.2.3 Disperion calculations
Distances up to which these concentrations are present as well as widths and areas are shown in Table 1. Of course these distances and areas are dependent on the atmospheric conditions present during the release. For the calculations unfavourable weather conditions were chosen: Pasquill-class F and wind speed 1.5 m/s.

As outlined in the previous paragraph, two approaches can be used to calculate source strength. Values shown in Table 1 were calculated using the point source approach. Values on the basis of the surface source approach were within 2% of those reported in Table 1.

<table>
<thead>
<tr>
<th>NH₃-concentration [mg/m³]</th>
<th>Criterium</th>
<th>Effect area</th>
<th>Length (distance from source) [km]</th>
<th>width [m]</th>
<th>Area [ha]</th>
</tr>
</thead>
<tbody>
<tr>
<td>10400</td>
<td>LC-50</td>
<td></td>
<td>1.9</td>
<td>95</td>
<td>17.9</td>
</tr>
<tr>
<td>3240</td>
<td>LC-01</td>
<td></td>
<td>4.0</td>
<td>185</td>
<td>74</td>
</tr>
<tr>
<td>70</td>
<td>AGW</td>
<td>~50</td>
<td>1800</td>
<td>9000</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>VGW</td>
<td>&gt;50</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
</tbody>
</table>

Table 1 Effect distance and areas

3.2.4 Casualties
To calculate the number of people affected by the NH₃ release, population densities should be known. Assuming a population density representative for an average urbanised area of 70 person / ha (not unrealistic in this densely populated part of The Netherlands) this would result in the following:
- In the LC-50 area (average 75% lethality): 940 casualties
- In the area between LC-50 and LC-01 (average 30% lethality): 1170 casualties
- The number of people needing medical attention will be many times larger that the 2110 casualties. As provision of medical help may be difficult in the flooded area the death toll as a result of the NH₃ release may be even higher.

3.3 Remarks

3.3.1 Effects
As mentioned above, dispersion of NH₃ will be strongly influenced by weather conditions. In the example above, unfavourable conditions were chosen. These conditions, however, may very well be incompatible with conditions likely to be present in case of a dyke breach. If more harsh weather conditions were assumed (pasquill class D and wind speed 9 m/s) effect distances would be about 1/10th of those shown in Table 1, resulting in approximately 55 casualties (as opposed to 2110).

3.3.2 Probability of the scenario to occur
Main purpose of the project is to assess the consequences of flooding, in this case the consequences of damage to industrial structures containing toxic compounds. The probability that the scenario outlined above will actually occur is not only dependent on local flood conditions, but also on measures taken by the company. In the current case the probability is reduced by the fact that both storage tank and
connecting pipes are positioned 2.5 m above ground level, by a (future) concrete bund around the tank, and by special measures to limit ammonia flow, or to isolate certain parts of the tank. Finally the tank is only used for 25% of the time.

4 Conclusions
In this study it was shown that severe consequences from flooding of industrial areas only are to be expected if the site is exposed to high energies, i.e. high volumes of water flowing with high velocities. During a flood in the Netherlands (as represented by a modelled dyke breach near Krimpen aan de Lek) such conditions will only exist in relatively small areas close to the breach. High water levels (and low water velocities) may be present over large areas. Resulting consequences will be less severe. Nonetheless, industrial installations, in particular storage tanks, may be dislodged and get damaged. Also floating debris may cause damage. Material thus released may be dispersed through the water or, through the air. Toxic substances in the (excess of) water are not expected to cause a significant number of (additional) casualties. However, volatile material, dispersed through the air may spread rapidly, even to non-flooded areas. Hence the study was focused on this material. Out of 8 locations on where large volumes of dangerous substances were stored and over 100 sites holding large volumes of oil products (like petrol stations) only one was subject to flooding conditions that could be expected to cause significant damage. This was a location where 86 tons of ammonia (NH₃) was present. Under unfavourable atmospheric conditions release of this volume could result in over 2000 deaths, and many more people needing medical attention. More realistic conditions, under which a dyke breach could be expected, could result in about 55 casualties. Although flood conditions might be such that a release could occur, local (safety) measures taken significantly reduce the probability of occurrence of such a scenario.
5 References


EFFECTS version 5: a computer program to calculate the physical effects and consequences of the release of hazardous material. Department of Industrial Safety, TNO-MEP, Apeldoorn, The Netherlands, 2003.


Appendix 1 Summary of accidents

SEQ.NR. 1
ACC NR (FACTS) 8393
ACC DATE 1964 0616
COUNTRY J
LOCATION TANKYARD
ACTIVITY STORAGE
CHEMICALS CRUDE OIL, OIL N.O.S.
FATALITIES
INJURIES
SCENE FIRE AND EXPLOSION OF 97 TANKS AT A TANKYARD OF REFINERY DUE TO EARTHQUAKE AND FLOODING
CONFIDENT
ACC DESC
CLASS * * *
EXT ABSTR An earthquake of magnitude 7.7 resulted in two major fires in this 7472/m³ per day refinery. The first fire, which started at the time of the quake, was the result of oil spillage over the sides of a floating roof tank. Friction sparks from the floating roof smashing against the sides of the tank caused ignition of the oil in the tank. Apparently the tank also developed leaks, which allowed more oil to spill. Later, when the seismic wave engulfed the area, the oil was spread by floodwaters. However, the oil did not ignite for about four hours. Six hours after the initial quake, an explosion occurred in another section of the refinery 366/m from the original tank fire. This explosion also spread to within 107/m of each other, they did not merge. Ninety-seven tanks containing 1.749E+5/m³ of crude oil and product were destroyed. Damage to operating units was extensive.

SEQ.NR. 2
ACC NR (FACTS) 4323
ACC DATE 1982 0215
COUNTRY ATLANT
LOCATION WINNING-AREA
ACTIVITY WINNING
CHEMICALS DIESEL OIL, LUBRICATION OIL, AVIATION FUEL
FATALITIES 84
INJURIES
SCENE RIG "OCEAN RANGER" CAPSIZED AND SUNK DURING SEVERE STORM
CONFIDENT
ACC DESC
CLASS * * *
EXT ABSTR

SEQ.NR. 3
ACC NR (FACTS) 1138
ACC DATE 1982 1203
COUNTRY USA
LOCATION RAILWAY
ACTIVITY RAILTRANSPORT
CHEMICALS AMMONIA ANHYDROUS
FATALITIES 3
INJURIES
SCENE SEVERE FLOODING CAUSES DERRAIL- MENT OF 3 TANKWAGONS
CONFIDENT
ACC DESC
CLASS
EXT ABSTR

SEQ.NR. 4
ACC NR (FACTS) 17907
ACC DATE 1984 0509
COUNTRY USA
LOCATION FACTORY
ACTIVITY STORAGE
CHEMICALS CARBON DIOXIDE (GAS)
FATALITIES
INJURIES
SCENE FLOOD WATERS ROSE TO A LEVEL ABOVE 2 SAFETY RELIEF VALVES ON CARBON DIOXIDE RECEIVER TANK CAUSING EXPLOSION
CONFIDENT
ACC DESC
CLASS * * *
A soft drinker manufacturer had a 3E+3/kg capacity carbon dioxide receiver tank at the plant. The tank contained 910/kg on the day of the explosion. The establishment was evacuated due to flooding river waters in the area. The plant was secured and evacuated. No employees were at the workplace. Suddenly, the storage tank rocketed 30/m into a nearby house.

Causes
The flood waters rose to a level above the 2 safety relief valves, causing the valves to freeze up or the pipe system to disconnect from the tank. The tank was then unable to vent. The pressure built up and the tank blew.

A flood-weakened bridge collapsed as an 80 car freight train crossed. Between 22 and 32 cars derailed. Some of the tank wagons and parts of the bridge fell into a muddy creek, where officials abandoned efforts to put out the raging fire. The police closed a city park, where more than 200 people were watching a soccer tournament. One car contained formaldehyde. Another car with butadiene exploded. Five persons were injured. One car of ethylene glycol ruptured and the chemical drained towards a creek. Railroad crews built dams on the creek bed to contain the product. A 3.2/km area was sealed off and 2000 people were evacuated.

Flooding of wood preservation site on which lindane and sodium pentachlorophenate were produced and stored caused a spill of 40/kg, which contaminated a river with a length of 14/km.

Diesel oil and fuel oil NR. 5 caused a spill of 40/kg, which contaminated a river with a length of 14/km.
INJURIES
SCENE VESSEL "AZALEA" SUNK BY A RUPTURED HULL. RELEASING FUEL POLLUTED THE COAST
CONFIDENT
ACC DESC
CLASS
EXT ABSTR

SEQ.NR. 9
ACC NR (FACTS) 10343
ACC DATE 1990 0424
COUNTRY USA
LOCATION LAKE
ACTIVITY PIPETRANSPORT
CHEMICALS CRUDE OIL
FATALITIES
INJURIES
SCENE PIPELINE RUPTURED AND THE SPILLAGE POLLUTED LAKE AND RIVER
CONFIDENT
ACC DESC
CLASS
EXT ABSTR

SEQ.NR. 10
ACC NR (FACTS) 13381
ACC DATE 1991 0226
COUNTRY GB
LOCATION TANKYARD
ACTIVITY STORAGE
CHEMICALS LIGHT NAPHTHA
FATALITIES
INJURIES
SCENE FLOATING ROOF OF STORAGE TANK SANK AND INTRODUCTION OF FOAM IGNITED THE NAPHTHA VAPOURS
CONFIDENT
ACC DESC
CLASS
EXT ABSTR
The accident occurred in a storage plant of a crude oil refinery. The capacity of the bulk storage floating roof tank was about 7E+6 kg.

Due to the mal-operation in the naphtha feeding line (snow loading may also have been a cause), a floating roof on a naphtha tank had sunk when it jammed and floats were flooded. To reduce the effects of the naphtha evaporation, that was cooling the tank to -4°C, foam was applied on the liquid surface. By mistake, the foam was applied into the middle of the tank surface (instead than on the border) and the static charges ignited the naphtha vapours. The ignition resulted in a progressive burning of vapours spreading over the surface of the tank. The on-site emergency plan was activated and the fire was fought by the refinery and the county fire services (between 1 and 50 rescue personnel were mobilized). The fire was extinguished in 3 hours.

The floating roof of the storage tank was destroyed. Material loss about 1.5E+6 ECU.

Causes:

Immediate causes:
Electrostatic load, component failure (tank failure).

Underlying causes:
Managerial/organisational omissions (insufficient operator training), appropriate procedures not followed.

After the accident, the following measures were established:
1. revision of procedures and training on static charges; 2. review of communication procedures.

SEQ.NR. 11
ACC NR (FACTS) 10924
ACC DATE 1991 0802
COUNTRY SU
LOCATION REFINERY
ACTIVITY PIPETRANSPORT
CHEMICALS OIL N.O.S.
FATALITIES
INJURIES
SCENE TORNADO HIT THE TOWN CAUSING WAVES AND FLOODING ; DAMAGED PIPELINE CAUSED POLLUTION.
CONFIDENT
ACC DESC
At a tank farm, 50-51 tanks, each containing 114/m3 of propane, floated from their support-foundations as river flooded over an earthen levee. Leaking propane vapours at pipe connections ignited with flash fires. 8000-11500 residents evacuated due to explosion fire risk from leaking tanks. Tanks were strapped down and attached to concrete base.

Crude oil was delivered to the refinery by sea and fed into the crude distillation unit, where it was separated into intermediate products, including naphtha and gas, kerosene, light diesel, heavy diesel and heavier components. The heavier components were fed into a vacuum distillation unit, which in turn fed a fluidised catalytic cracking unit (FCCU). The explosion occurred in the FCCU, which was continuous process unit converting long chain and cyclic hydrocarbons into smaller hydrocarbon products used mainly in fuels.

A severe thunderstorm passed over the refinery between 0720 and 0900. Lightning strikes resulted in a fire on the crude distillation unit and in a 0.4/s power loss and subsequent power dips throughout the refinery. Consequently, numerous pumps and overhead fin-fan coolers tripped repeatedly, resulting in the main crude column pressure safety valves lifting. Also major process units, including those within the fluid catalytic cracking complex. This cracking complex, which included the FCCU, vacuum distillation, butamer and alkylation unit and an idle hydrogen plant, is a joint venture of 2 oil refining companies.

The refinery crude unit was shut down following ignition of vapour escaping from the main crude column pressure safety valves by a subsequent lightning strike. Except for the FCCU itself, all units in the cracking complex were also shut down.

A fault in the flow of hydrocarbon to the de-ethaniser caused a pressure build-up of hydrocarbon in the de-butaniser unit, where the liquid was subject to heat. When the flow of hydrocarbon was restored a valve failed to reopen and release the build-up in the de-butaniser. Control-room systems wrongly reported that the valve had reopened.
The set up of the displays on the operators’ control system meant that they were unable to diagnose the problems or provide an overview of the process and its mass balance.

It became apparent in the control room that the de-butaniser was becoming too logged. To relieve the pressure another valve was opened, allowing the hydrocarbon to enter an inter-stage drum. This drum became flooded very quickly and tripped shutdown. This meant that large volumes of flammable hydrocarbon gas went in the plant and had to be vented to the flare stack to be burned off. This resulted in a very high level in the flare knock-out drum.

The level of liquid increased when an operator drained the liquid from an interstage drum directly to the flare line. When a further build-up of liquid in the interstage drum occurred, the gas vented to the full flare drum forced liquid into the knock-out drum discharge pipe. This pipe, known to be corroded, was not designed to carry liquid. A pulsing leak appeared at the flare drum discharge elbow where the outlet line had ruptured and fallen to the ground. 20E+3/kg hydrocarbon liquid and vapour mixture released from this flare system became an explosive mixture that drifted within the process area prior to being ignited by a heater. The explosion, which occurred at 1323 hours, was centred in the process area approximately 110/m from the FCC on-plot flare drum.

Following the explosion, a number of isolated fires continued to burn at locations within the FCC, Butamer, and alkylaition units. In view of the entrained hydrocarbons in damaged areas of the plant and a non-operative flare system, these small fires were allowed to burn out under controlled conditions with the largest fire being extinguished on the morning of 0727. The fire fighting was handled by the refinery emergency services with assistance from another fire brigade.

As a result of this incident, an estimated 10% of the total refining capacity in GB was lost until this complex was returned to service. The business interruption loss for this incident is estimated at 70E+6 USA dollars, which reflects 4.5/months of downtime. The property damage was 77.5E+6 USA dollars.

Eye-witnesses reported flames of 30/m. The blast caused damage to buildings, tanks, and columns. The Control Room had some blast protection features but had suffered internal damage due to a door being open at the time of the explosion, as the earlier power interruptions had rendered the air conditioning control inoperative.

Windows were broken at a distance of 3/km. Only 26 persons were slight injured. This was mainly because the incident occurred at the weekend and some contractors left a building only minutes before it was destroyed in the explosion.

The refinery, which is run in partnership by two oil companies, has been fined 200 000 GB pounds and were ordered to payment of 143700 GB pounds prosecution costs. The refinery had already paid out 180000 GB pounds compensation for damage to public property and installed a 2E+6 GB pounds monitoring system.

Causes:

The direct cause of the explosion was a combination of failures in management, equipment and control systems.

Recommendations

The HSE made 14 recommendations.

1 Safety management systems should include means of storing, retrieving and reviewing incident information from the history of similar plants.

2 Safety management systems should have a component that monitors their own effectiveness.

3 Display systems should be configured to provide an overview of the condition of the process, including, where appropriate, mass and volumetric balance summaries.

4 Operators should know how to carry out simple volumetric and mass balance checks whenever flow or level problems are experienced within a unit.

5 The training of staff should include:
   a. assessment of their knowledge and competence for their actual operational roles under high stress conditions;
   b. clear guidance on when to initiate controlled or emergency shutdowns and how to manage unplanned events, including working effectively under the stress of an incident.

6 The use and configuration of alarms should be such that: safety critical alarms. Including those for flare systems, are distinguishable from other operational alarms; alarms are limited to the number that an operator can effectively monitor; and ultimate plant safety should not rely on operator response to a control system alarm.

7 Safety critical plant requirements on which the safety of a process relies, i.e. whose failure could lead to hazardous events, should be identified. Any safety systems used to protect against hazardous events should be specified, and subsequently designed, based on an appropriate hazard risk analysis so that the functions to be carried out and the necessary level of integrity are systematically determined.

8 In new build or re-equipping projects and in reviews of existing plant layouts, a risk assessment should be carried out with regard to the location, and suitability of construction, of the buildings and the plant.

9 In processes that employ a flare system, there should be effective arrangements for the removal of slopes from a flare knock-out drum which ensure that the removal is promptly initiated and at an adequate rate to prevent the drum from overfilling.

10
There should be a formal, controlled procedure for hazard identification and operability analysis for modifications (including emergency modifications) that ensures that all safety issues identified at the design stage are reflected in how the modification is constructed and used.

11 All safety critical parts of plant should be included in comprehensive inspection programmes.

12 Inspection programmes for corrosion should err on the side of caution, with regard to the number and location of measurement sample points, concentrating on measurement sample points where greater (or less uniform) metal loss is foreseeable.

13 All foreseeable operational conditions, not just pressure, should be taken into account when setting the minimum acceptable thickness for pipe and vessel walls.

14 Fire brigades, in consultation with appropriate major hazard installations, would be wise to look at emergency plans, particularly in respect of the availability of adequate water supplies for fire fighting and vessel cooling, to deal with the worst case scenario.

Three former oil refinery workers who suffered mental trauma after the explosion have been awarded a total of 839000 GB pounds.

A 54-year-old worker, who was working as a process operator close to the cracking unit at the heart of the blast, was awarded for pain and suffering loss of amenity. He suffered from depression, flashbacks and poor concentration (Post Traumatic Stress Disorder. As a consequence his job was terminated and he was retired early by the company.

Two other men, 59 year old and 53 year old were awarded 210019 and 289021 GB pounds respectively.

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SEQ.NR. 15
ACC NR (FACTS) 15162
ACC DATE 1994 1017
COUNTRY USA
LOCATION CHEM-FACTORY
ACTIVITY PROCESSING
CHEMICALS ETHYLENE (PRESSURIZED), POLYETHYLENE, OLEFINES/AROMATES, ACETYLENE
FATALITIES
INJURIES
SCENE HEAVY RAINS AND FLOODING CAUSED SUCCESSFUL PLANT SHUT DOWN HOWEVER THE DAMAGE WAS EXTENSIVE
CONFIDENT
ACC DESC
CLASS * * *
EXT ABSTR Heavy rains resulted in extensive flooding from surface water as well as overflowing streams. Flood water covered the entire plant in depth ranging from 0.6-1.5/meter.

Plant management anticipated the flooding of the plant and was successful in shutting down all six process units in an orderly manner. Additional, plant personnel were successful in relocating the smaller and lighter property items to higher ground. This effort notwithstanding, the flood water caused extensive damage, mainly to computers, electrical substations, switchgear, pumps, motors and buildings. At least 350 electric motors varying from 5 to 20 horsepower were completely submerged and required replacement while the larger electric motors up to 1,500 horsepower were disassembled, baked out, and repaired.

The loss of property was estimated at 25E+6 USA dollars.

The plant was shut down for approximately 2/months as a result of this flooding. During this period, the ethylene, polyethylene, olefine, and acetylene black production was shut down resulting in a business interruption loss estimated at 85E+6 USA dollars.

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SEQ.NR. 16
ACC NR (FACTS) 12029
ACC DATE 1994 1020
COUNTRY USA
LOCATION RIVER
ACTIVITY PIPETRANSPORT
CHEMICALS DIESEL OIL, PETROLEUM PRODUCTS, OIL RESIDUE, OIL-WATER MIX
FATALITIES
INJURIES 547
SCENE PIPELINES RUPTURED DUE TO HEAVY FLOODING AND PETROLEUM PRODUCTS FLOWED INTO THE RIVER AND CAUGHT FIRE
CONFIDENT
ACC DESC
CLASS * * *
EXT ABSTR Pipelines ruptured on the San Jacinto River spilling petroleum (products) gasoline and diesel oil. Between October 14 and October 21, 1994, some 380-508/mm of rain fell on the San Jacinto River flood plain near Houston, Texas resulting in dangerous flooding that far surpassed flooding experience in the region. The floods forced over 14,000 people to evacuate their homes and resulted in 20 deaths. Due to the flooding, 8 pipelines ruptured and 29 others were undermined both at river crossings and new channels created in the flood plain. More than 5655/m3 of petroleum and petroleum products were released into the river. Ignition
of the released products within flooded residential areas resulted in 547 people receiving (mostly minor) burns and inhalation injuries. The spill response costs were in excess of 7E+6 USA dollars and estimated property damage losses were about 16E+6 USA dollars.

The gasoline almost immediately ignited and continued to burn as of 0830 local time on 21 October, the diesel oil caught fire somewhat later.

The gasoline was still burning at 26th October. The fire of the diesel pipeline was extinguished at 24th October.

The river has been cleaned with all available material and man-power.

The number of pipelines ruptured and damaged during flooding, and magnitude of the petroleum releases and spill response efforts again emphasized the threats posed to public safety and the environment by petroleum transportation by pipeline. Although one of the safest means for transporting petroleum, pipeline transportation also poses great risk potential to the environment because of the large volumes of hazardous liquids that can be released when a rupture occurs. Also, in a pipeline transport situation, as opposed to other transport options, there is a greater likelihood of releasing petroleum into environmental consequences of releases from pipelines have been expressed by the Congress, the States, and local authorities.

The number of pipelines damaged during flood, the volume of petroleum products released, and the massive quantities of personnel and equipment needed to respond to the spills prompted the NTSB to undertake this special investigation to assess:

1. the adequacy of Federal and industry standards on designing pipelines in flood plains;
2. the preparedness of pipeline operators to respond to threats to their pipelines from flooding and to minimize the potential for product releases;
3. the preparedness of the Nation to minimize the consequences of petroleum releases. The report also addresses the need for effective operational monitoring of pipelines and for use of remote- or automatic-operated valves to allow for the prompt detection of product releases and rapid shutdown of failed pipe segments.

As a result of its investigation, the Safety Board made nine safety recommendations: one to the Research and Special Programs Administration, five to the National Response Team, and one each to the American Petroleum Institute, the Association of Oil Pipe Lines, and the Interstate Natural Gas Association of America.

Conclusions
1. The design bases of most pipelines undermined of ruptured during the flood did not include study of the flood plain to identify potential threats; rather, operators used only general design criteria applicable at the time the pipelines installed.
2. Standards for designing pipelines across flood plains are needed to define the multiple threats posed to pipelines and to address the research, study, and future considerations that must be used for designing pipelines and periodically re-evaluating the integrity of their designs during their operating life.
3. Most operators of pipelines crossing the San Jacinto River flood plain continued operations without evaluating the capability of the pipeline design to withstand the threats presented by the flood.
4. Few pipeline operators took effective response actions during the San Jacinto flood to minimize the potential for product releases.
5. Pipeline operators would have been more likely to have implemented early shutdown/or purging of products from pipe segments crossing the San Jacinto flood plain had the Research and Special Programs Administration required them to develop plans for responding to substantial threats of a pipeline failure and product discharge.
6. The response by local, State, and Federal government agencies to the flood emergency was well-managed and effective.
7. Failed liquid pipelines continue to release excessive volumes of petroleum and liquid products into the environment because the Research and Special Administration has not established requirements for rapid detection and shutdown of failed pipe segments, and the liquid pipeline industry has not incorporated means for rapidly detecting, locating and shutting down failed pipe segments.
8. Risks to workers and the public were increased significantly when the unified command conducted an in-situ burn without having in place appropriate checks and balances to ensure that approved procedures and requirements were followed explicitly.
9. Spill management personnel responding from other regions of the country and trained on different incident command procedures created communications, command, and control difficulties because they were not familiar with the incident command structure and procedures in use in the Galveston Bay area.
10. Implementation of the unified incident command structure and operational principles in the National Response Team's Technical Assistance Document Incident Command System/Unified Command will enhance the overall preparedness for responding to petroleum spills.
11. Many lessons on improving the area's spill response preparedness were not learned primarily because a comprehensive after-action critique was not conducted.
Recommendations
To the National and Special Programs Administration:
* Require operators of liquid pipelines to address, in their Oil Pollution Act of 1990 spill response plans, identifying and responding to events that can pose a substantial threat of worst-case product release.

To the National Response Team:
* Make your membership aware of the circumstances and nature of the events in the October 1994 environmental response at Houston, Texas, specifically in regard to the need for coordinating all planning and operational activities prior to conducting in-situ burn countermeasures.
* Motivate National Response Team agencies to integrate into their area contingency plans the command and control principles contained in Technical Assistance Document Incident Command System/Unified Command and encourage them to train all personnel assigned management responsibilities in those principles.
* Include procedures for implementing your Unified Command/Incident Command System that will ensure that all safety-critical operations are coordinated with parties at risk.
* Establish guidance calling for Federal On-Scene Coordinators to conduct a comprehensive after-action critique of each spill response to incorporate the observations of all participating agencies to identify improvements needed in equipment, communications procedures, guidance, techniques, and management.
* Request that Federal On-Scene Coordinators document and forward to National Response Team headquarters all lessons learned developed from response critiques for review and implementation nationwide as appropriate.

To the American Petroleum Institute:
* Take the lead to develop, in cooperation with the Interstate Natural Gas Association of America and the Association of Oil Pipe Lines, design and construction standards adequate for pipelines to safely cross flood plains and streambeds, including the development of recommended practices for periodically reassessing crossing designs in light of changes that have occurred in the flood plain or streambed.

To the Association of Oil Pipe Lines and the Interstate Natural Gas Association of America:
* Develop, in cooperation with the American Petroleum Institute, design and construction standards adequate for pipelines to safely cross flood plains and streambeds, including the development of recommended practices for periodically reassessing crossing designs in light of changes that have occurred in the flood plain or streambed.

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SEQ.NR. 17
ACC NR (FACTS) 12134
ACC DATE 1994 1102
COUNTRY ET
LOCATION STORAGE/DEPOT
ACTIVITY STORAGE
CHEMICALS AVIATION FUEL, FUEL OIL
FATALITIES >277
INJURIES >1
SCENE STORM DAMAGED MILITARY FUEL-TANKS, FLOOD WATER BROUGHT FIRE TO VILLAGE AND KILLED MORE THAN 277 PEOPLE
CONFIDENT ACC DESC
CLASS * * *
EXT ABSTR An estimated 16700 m3 of motor and aircraft fuel spilled when military fuel tanks 320 km south of Cairo were damaged in a storm. Flood waters spread burning fuel through the village, razing 200 homes and killing more than 277 people.

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SEQ.NR. 18
ACC NR (FACTS) 12522
ACC DATE 1995 0125
COUNTRY CH
LOCATION STORAGE/DEPOT
ACTIVITY STORAGE
CHEMICALS PAINT, CHROMIC ACID CRO3
FATALITIES
INJURIES
SCENE FLOODING OF A RIVER FILLED CELLAR CONTAINING CHEMICALS
CONFIDENT ACC DESC
CLASS * * *
EXT ABSTR Die Ueberschwemmung der Aare und der Ruckstau in der Kanalisation führte zum Eindringen von 1200/m3 Wasser in einen 6000-30000/l chemische Hilfsstoffe enthaltenden Keller einer Farbenfabrik. Das Wasser/Chemikalien-Gemisch konnte analytischen Untersuchungen entsprechend entsorgt werden. Die Kosten beliefen sich auf einige 100000 SFr.
SEQ.NR. 19
ACC NR (FACTS) 12716
ACC DATE 1995 0303
COUNTRY AUS
LOCATION STORAGE/DEPOT
ACTIVITY STORAGE
CHEMICALS DIESEL OIL
FATALITIES
INJURIES
SCENE A STORAGE TANK COLLAPSED AND SPILT ITS CONTENTS AFTER EXTENSIVE FLOODING UNDERMINED FOUNDATION FOR TANK SUPPORTS
CONFIDENT ACC DESC
CLASS * * *
EXT ABSTR The support structure of a 15/kilolitre elevated diesel storage tank collapsed following torrential rain and subsequent flooding which destabilised underlying soil. The tank was pierced on impact allowing the entire 13000/ litres of diesel within it to escape. The spilt diesel was retained within the earth bund and soaked into the soil. The contaminated soil was later removed from site for disposal. Due to the remote nature of the site there was no threat to public safety and no contamination of drinking or ground water. The company involved has reviewed the flood susceptibility of their storage to prevent a recurrence.

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SEQ.NR. 20
ACC NR (FACTS) 13208
ACC DATE 1995 0723
COUNTRY ROK
LOCATION SEA
ACTIVITY NAVIGATION
CHEMICALS BUNKER FUEL OIL, CRUDE OIL, BUNKER FUEL OIL
FATALITIES
INJURIES
SCENE TANKER GROUNDED CAUSING EXPLOSION, FIRE AND RELEASE OF BUNKER FUEL OIL AND PART OF CARGO WAS SAVED BY SALVOR
CONFIDENT ACC DESC
CLASS * * *
EXT ABSTR A tanker was discharging a full cargo when a typhoon warning led to the tanker leaving the port. The typhoon Faye caused the 276,000/dwt very large crude carrier (VLCC) "Sea Prince" grounded onto the rocks while carrying a part cargo of some 80-83E+6/kg of crude oil. The engine room and accommodation area were damaged by explosions and fire and, in the immediate aftermath, some 0.7E+6/kg of bunker fuel and an unknown amount of cargo leaked to the sea. It was the worst pollution incident in more than 3/years. Booms had been positioned around the tanker and about 35 ships were attempting to contain the spill. An oil slick 32/km long was reported off the Korean peninsula and it feared that the oil would spread to the Hanryo Sea National Park. Over the next few weeks additional small volumes of crude oil leaked from the half-submerged section of the hull. The tanker's owner engaged a salvor to save the tanker and her remaining cargo under a Lloyd's Open Form 1995 on July 28. Initially the salvor intended to refloat the ship with the remaining cargo on board and tow her to a safe place for discharging the cargo. However, experts cautioned against this course of action, not least as it might nullify the possibility of claiming against the International Oil Pollution Compensation Fund (IOPC) should any pollution arise as a result of the operation. The salvor then decided to remove the remaining cargo before attempting to refloat the ship and a total of 80E+6/kg of oil was transhipped to barges between August 6 and August 22. At this point it was estimated that there was a further 950E+3/kg of crude oil still onboard and this was dosed with dispersants to ensure that, should the oil be lost during salvage operations, it would disperse quickly in the water column. The salvor intended to refloat the ship and tow her to a ship breaker or repair yard but, shortly after the transhipment operation was completed, a typhoon passed close to the site of the grounding and the sailor had to suspend all activities. Further investigation of the wreck after the bad weather passed revealed that further serious structural damage had been suffered and technical experts agreed that there was an unacceptable risk of the ship breaking up during the refloating operation. In view of this, the owner decided to abandon attempts to save the ship and contracted with Smit International for her removal. She was eventually refloated on November 26, 1995 and towed out of Korean waters. Korean authorities are carrying out an investigation into the incident. The hull and machinery of the five year old tanker was insured for 50E+6 USA dollars.

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SEQ.NR. 21
ACC NR (FACTS) 13820
ACC DATE 1995 0810
COUNTRY J
LOCATION OTHER
ACTIVITY PIPETRANSPORT
CHEMICALS: LIQUIFIED NATURAL GAS (LNG)

FATALITIES

INJURIES

SCENE: A PIPELINE WAS RUPTURED BY LAND-SLIDE CAUSED BY HEAVY RAINS & FOLLOWING FIRE LASTED FOUR HOURS

CONFIDENT

ACC DESC

CLASS: **

EXT ABSTR: A 350/mm diameter, 23.5/km pipeline was ruptured by a land-slide caused by heavy rains in the area. There were no casualties and processing plants were not damaged. A four hour fire resulted from the break.

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SEQ.NR. 22

ACC NR (FACTS) 17954

ACC DATE 1997 0428

COUNTRY USA

LOCATION OTHER

ACTIVITY PIPETRANSPORT

CHEMICALS: CRUDE OIL

FATALITIES

INJURIES

SCENE: DUE TO FLOOD WATERS PIPELINE RELEASE OCCURRED CAUSING MAJOR CRUDE OIL SPILL AND POLLUTION OF RIVER

CONFIDENT

ACC DESC

CLASS: **

EXT ABSTR: A major crude oil spill occurred when a 304.8/mm pipeline developed a leak due to flood waters. 79.5/m3 of crude oil released into a river. The pipeline has been shutdown and the release was secured. 3 containment booms have been placed 161/km downstream of the spill site near a town.

EPA has notified the US Fish and Wildlife Agency due to possible threat to a National Wildlife Refuge.

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SEQ.NR. 23

ACC NR (FACTS) 15765

ACC DATE 1998 0129

COUNTRY PACIF.

LOCATION SEA

ACTIVITY NAVIGATION

CHEMICALS: ZINC COMPOUNDS, COPPER, FUEL OIL (HEAVY), DIESEL OIL

FATALITIES

INJURIES

SCENE: HEAVY SEAS CAUSED SHELL DAMAGE OF VESSEL FLOODING CARGO HOLD NR.1 TO THE WATERLINE AND FORCING TO REPAIR THE SHELL

CONFIDENT

ACC DESC

CLASS: ***

EXT ABSTR: Divers found severe structural damage to the side shell of the number 1 cargo hold and fractures to the number 3 and 4 cargo hatch coamings of the M/V Ince Express.

The damage occurred due to heavy seas encountered during four storms. The vessel was even keel. Number 1 cargo hold was flooded to the waterline. The vessel was loaded with 5532E+6/kg of zinc concentrates in hold #3, 17102E+6/kg of copper concentrates in holds 1 and 4, 14407E+6/kg of beet pulp pellets in holds 2 and 5. The vessel has approximately 830E+6/kg of heavy fuel oil, 65E+6/kg diesel oil, and 14E+6/kg of lube oil on board. The Captain of the Port had ordered the vessel detained until satisfactory repairs could be made. After the work was completed, the Captain of the Port released the vessel from the detention order. The vessel remains off of the island and will sail upon release of release of documents by the contractor.

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SEQ.NR. 24

ACC NR (FACTS) 17817

ACC DATE 1999 0918

COUNTRY USA

LOCATION STORAGE/DEPOT

ACTIVITY STORAGE

CHEMICALS: PROPANE, ACETONE, NITRATES N.O.S., BUTYL ALCOHOL

FATALITIES

INJURIES

SCENE: DUE TO HURRICANE AND FLOODING SEVERAL DRUMS & TANKS WITH SEVERAL CHEMICALS FLOATING ON RIVER

CONFIDENT

ACC DESC

CLASS: ***
Flash flooding following the passage of a hurricane, resulted in more than 150 drums and tanks floating in a river. Coast guard and contractors have recovered 155 assorted 208/l drums and several tanks. The drums were being delivered to an environmental agency staging area. The drums and tanks contained propane, acetone nitrate, butyl alcohol, methyl hepenone, tert butyl alcohol, heptane, methylpropylamine, adhesives with several constituents, several unknown and several empty drums.

A flash flood broke the country's main crude oil export pipeline sending a 70E+3/kg crude oil down a river and into 2 lakes. The crude oil spilled for 18/hours before the pump was turned off. The spill was killing wildlife and affected hundreds of farmers in the area who depend on the river. The population in the region depend on the river for fishing, for their drinking water and as a source of crop irrigation for farming. Hundreds of dead birds and fish were seen along the river shores, which were covered with a layer of oil.

The government deployed military and civil defence personnel to help mop up oil. Cleanup equipment was expected to arrive from USA.

The government was considering fining the pipeline company, because it did not notify the authorities about the oil spill until 24/hours after it had occurred.

Emergency crew prepared to resume their search up for 3 people missing after a deadly weekend fire triggered by heavy rains from the remnants of a tropical storm. Firefighters and police would begin combing through the charred rubble of a building in an apartment complex. Four people died when an apparent natural gas explosion set off by rising flood waters tore through the eight-unit structure, causing section of the structure to cave in. Fire quickly swept the building and 2 adjacent structures and raged for hours whiled flooding kept fire-fighters standing by helpless, their equipment unable to breach the flood waters that surrounded the fire scene. About 30 apartment residents were rescued by boat. Three people were still unaccounted for, but authorities could not say whether they had been trapped inside the apartment building.

The cause of the fire was under investigation, but officials believe flood waters dislodged a natural gas line into the complex, setting the stage for a fiery explosion. Emergency crews, which searched in vain for 3 missing residents, were also expected to return to a nearby creek, which flooded the apartment complex after being overwhelmed by heavy rains from the tropical storm.

Over the weekend, the storm system dumped as much as 229/mm of rain on counties, forcing hundreds of people to evacuate.
The Environment Agency report concluded that the licence in force set a reasonable standard of control with necessary and enforceable conditions but identified some areas for improvement. The site was inspected at the appropriate frequency and the Area team gave priority to improving working practices possibly at the expense of taking formal enforcement action. In December 1997 operations at the site gave rise to a discharge of blue dye which affected properties in the village. This was fully investigated and the Environment Agency sought to prosecute the company. After a number of adjournments the case was due to be heard at magistrates on 24 July 2000. Immediately before the hearing the company admitted they had committed an offence and accepted a Formal Caution and agreed to pay the Agency’s costs of over £21000 GBP pounds. The implementation of the special waste procedures by Environment Agency staff was considered to be good. The Environment Agency response to the incident was considered to be good and there were many supportive comments from external bodies regarding the Environment Agency’s role. A number of learning points have resulted from the internal investigation and will be taken into account both at a local level and when revising national policy.

**Incident**

A fire occurred at approximately 0200 hours in a waste storage area at a waste treatment facility. The seat of the fire was in the southwest corner of the waste transfer station compound that was used for the storage of laboratory smalls and some flammable liquids. The first call of the emergency services was logged at 0219 hours and the Fire Service arrived on scene within 6 minutes. Environment Agency staff attended immediately and were able to give advice to the fire fighting operation. HSE and other parties also attended during the incident. The Fire Service was unable to approach the site for some hours because of the intensity of the fire and small aerosols cans exploding. The incident occurred at a time of severe storms with gale force winds and very heavy rain. Wind speeds peaked at 80-96km/h. These extreme weather conditions continued to cause problems throughout the day. The Fire Service set-up a forward command post in the car park of a public house, approximately 1km south of the site. At approximately 1040 hours, this site was evacuated due to the expected flooding of the lane (although this did not actually occur until later in the week). The command post was re-established at the southern end of the line, approximately 2km from the site. The Fire Service accessed the site via the fields to the south, due to the very strong prevailing wind from the south. Throughout the day, water and foam were applied to the fire which was concentrated at the south end of the site. The fire was eventually fully extinguished by 1800 hours, having burned for approximately 16 hours, although a number of drums involved in the fire continued to smoulder. The fire was restricted to the waste transfer area and did not affect the bulk tank storage on site. Most of the firewater was retained on site, by site containment measures, but some contaminated water escaped and had to be pumped back. The Fire Service remained in attendance overnight. They relinquished control of the site early the next morning, the 31 October, allowing access on to the site for HSE and the Environment Agency to begin investigation of the incident. The fire resulted in the Police evacuating approximately 60 local people at the time, who were allowed to return to their homes that evening, the 30 October. The evacuation itself was hampered by the fumes from the fire. 13 people sought medical advice (mostly emergency service personnel but including some local residents) although none required admission to hospital. On 1 November the company waste management license was suspended to prevent the site receiving any more wastes whilst maintaining the environmental protection controls. On 2 November, because of imminent flooding of the site, and following the issue by the Environment Agency of an anti pollution Works Notice, the company working under Environment Agency and HSE guidance, moved waste to compound 3; the highest area on the site. The site was flooded by 3 November and monitoring of conditions by the Environment Agency continued using a helicopter. On 5 November, access to the site was gained by the Environment Agency using a boat. There was concern over one fire-damaged 205l drum that appeared to have reacted. It was found to contain selenium, cadmium and arsenical compounds and had the potential to be continuing source of emissions. On 6 November, access to the site was again made by boat and a joint audit carried out by the Environment Agency and HSE. During this audit seven 25l containers labelled solvent contaminated with BSE were discovered. The site was subject to on-going air monitoring because of the hazard posed by the selenium drum since access problems prevented its removal from site. When all the remaining material had been secured, the site was evacuated and Environment Agency staff continued to monitor it by helicopter and boat. No materials escaped from the site during the flooding.

The site was unoccupied at the time of the incident. A plume of smoke from the fire was observed to be driven by the high south westerly winds in a predominantly north easterly direction over the village. During the fire, approximately 60 people were evacuated from their homes by the emergency services. Thirteen persons, mainly emergency service personnel, were taken to hospital as a precautionary measure during the fire but none was admitted. On 3 November 2000 the site, which is alongside a river, was subject to flooding and remedial actions had to be taken to ensure that fire-damaged and other material on site was moved beyond the reach floodwaters and the site otherwise made safe. Serious flooding continued until 22 November and high flood water levels continue to threaten the site which flooded again in December. Residents were again evacuated when the site flooded as a precaution against any further incidents occurring.

The clearance of the site commenced on the 27 November 2000 with the removal of the damaged drum containing selenium and the containers of solvent possibly contaminated with BSE. By 6 December it was apparent the site would flood again and by the time the site flooded on 8 December over 4000 kg of the waste had been removed, including over 80% of the drummed waste on site.
Most of the drummed waste had been removed from the site by the end of January 2001. Items that remained were 30 drums of laboratory smalls, fire damaged asbestos and some pallets of fire damaged gas cylinders. In the weeks following the incident there was a large number of reports of illness from local residents. Following the fire, serious concerns about the operation of the site, and any possible off-site effects from the incident, were raised by local residents. Communication channels were set-up to provide information and to listen to the concerns of residents and their representatives. These channels included a local drop-in centre, daily question and answer briefings and media interviews.

Chemicals involved
The inventory of substances involved in the fire: 0.1E+3/kg of cyanide solutions, 0.8E+3/kg of pesticide residues, 0.2E+3/kg of mercury based pesticide, 0.12E+3/kg of triozine biocide, 0.8E+3/kg of metals (nickel, copper, aluminium), 0.8E+3/kg of flammable smalls, 1E+3/kg of ammonium chloride, 49.2E+3/kg of paint thinners, 21.1E+3/kg of chlorinated solvents, 4.8E+3/kg of acrylic resin, 8E+3/kg of paint stripper, mixed aerosols, 20.5E+3/kg of mixed solvents, 0.8E+3/kg of acidic resin, 0.8E+3/kg of magnesium oxide/nitride, 0.6E+3/kg of aluminium chloride, 2.2E+3/kg of methylated spirit, 6E+3/kg of methanol, 34E+3/kg of adhesives, 8.8E+3/kg of lab smalls, 12E+3/kg of isopropanol, 4.8E+3/kg of acetone and batteries.

Probable cause
The January 2001 Joint Report to the Deputy Prime Minister contained information on a number of potential initiating events for the fire. The on-going investigation is strongly indicating that the two most credible are chemical initiation or arson. HSE is undertaking experimental work to examine the potential risks from the storage of laboratory smalls at the company and the potential propagation of the fire.

Lessons learned
The Environment Agency, HSE and other organizations involved in the incident are determined to ensure that lessons are learned. Considerable progress has already been made with Action Plans developed and a number of actions already implemented.

The Environment Agency has developed a National Action Plan to ensure that lessons from the incident are learned across the country. A national review of the management of radioactive substances at facilities similar to the company site and a desktop review of all licenses issued to the company has already been undertaken. The Environment Agency has also established a project team to take forward the actions relating to the company site. The planning issues surrounding the location and use of the site are being investigated by the County Council. The incident also highlighted the issues involved in siting installations of this type in locations where there is a risk of extensive flooding. The Department of the Environment Transport and the Regions (DETR) is now considering the lessons learned from the incident and the implications for land use planning policy.

A specialist HSE inspector has visited a sample of sites similar to the company throughout the United Kingdom and reviewed the arrangements in place for the safe storage of packaged dangerous substances. An inspection initiative is planned to ensure that all chemical waste treatment sites have effective health and safety arrangements in place.

The Major Incident Co-ordinating Group (MICG), made up of senior managers from the emergency services and other organizations have held a de-brief on the incident. They identified a number of actions to be taken forward to ensure lessons are learned and an action plan has been prepared. Key issues identified are, the need to ensure that there is a good knowledge and understanding of roles and responsibilities between the relevant agencies and the development of a system between the relevant agencies to give health advice to the public during major incidents.
CHEMICALS DIESEL OIL, BENZINE (FP<21/C), LUBRICATION OIL
FATALITIES
INJURIES
SCENE A STORAGE TANK AT AN ABANDONED HOSPITAL SPILLED DIESEL FUEL ALONG WITH BENZINE & LUBE OIL CAUSING POLLUTION & EVACUATION
CONFIDENT ACC DESC CLASS * *
EXT ABSTR A storage tank at an abandoned hospital spilled 11.9/m3 of diesel fuel when a tropical storm impacted the area. The diesel fuel along with some gasoline and lube oil spilled into a nearby river.

Fourty families, from the surrounding area, were evacuated due to the spill of diesel fuel and the flooding associated with the tropical storm.

Booms had been deployed and a contracted company had been hired to conduct the cleanup.

SEQ.NR. 30
ACC NR (FACTS) 17738
ACC DATE 2002 0123
COUNTRY USA
LOCATION STORAGE/DEPOT
ACTIVITY STORAGE
CHEMICALS DIESEL OIL, PROPANE
FATALITIES
INJURIES
SCENE DUE TO HEAVY FLOODING TWO STORAGE TANKS WITH DIESEL OIL AND PROPANE, BROKE LOOSE AND DRIFTED DOWN RIVER TOWARDS DAM
CONFIDENT ACC DESC CLASS * *
EXT ABSTR At about 1555 hours due to heavy flooding, a 3.79/m3 storage tank filled with diesel fuel and a 380/liters storage tank filled with propane, broke loose from an unknown location and were drifting down river towards the dam. It is unknown if any material has been released.

A highway, which crossed the dam, was closed to all traffic.
General Appendix: Delft Cluster Research Programme Information

This publication is a result of the Delft Cluster research-program 1999-2002 (ICES-KIS-II), that consists of 7 research themes:
- Soil and structures,
- Risks due to flooding,
- Coast and river,
- Urban infrastructure,
- Subsurface management,
- Integrated water resources management,
- Knowledge management.

This publication is part of:

<table>
<thead>
<tr>
<th>Research Theme</th>
<th>Risk of Flooding</th>
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<tbody>
<tr>
<td>Baseproject name</td>
<td>Measuring, Monitoring and Exploration</td>
</tr>
<tr>
<td>Project name</td>
<td>Monitoringsfilosofie Hermes</td>
</tr>
<tr>
<td>Projectleader/Institute</td>
<td>Prof. A.C.W.M. Vrouwenvelder</td>
</tr>
<tr>
<td>Project number</td>
<td>02.03.03</td>
</tr>
<tr>
<td>Projectduration</td>
<td>01-02-2002 - 01-07-2003</td>
</tr>
<tr>
<td>Financial sponsor(s)</td>
<td>Ministry of Public Works, Road and Water Management</td>
</tr>
<tr>
<td>Projectparticipants</td>
<td>GeoDelft</td>
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<td>WL</td>
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<td>TNO</td>
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<td></td>
<td>Delft University of Technology</td>
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<td></td>
<td>Twente University</td>
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<td>Alterra</td>
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<td>Total Project-budget</td>
<td>€ 450.000</td>
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<tr>
<td>Number of involved PhD-students</td>
<td>2</td>
</tr>
<tr>
<td>Number of involved PostDocs</td>
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Delft Cluster is an open knowledge network of five Delft-based institutes for long-term fundamental strategic research focussed on the sustainable development of densely populated delta areas.
**Theme Management team:** Ground and Construction

<table>
<thead>
<tr>
<th>Name</th>
<th>Organisation</th>
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<tbody>
<tr>
<td>Prof. J.K. Vrijling</td>
<td>Delft University of Technology</td>
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<tr>
<td>Ir. E.O.F. Calle</td>
<td>GeoDelft</td>
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<td>Prof. A.C.W.M. Vrouwenvelder</td>
<td>TNO</td>
</tr>
</tbody>
</table>

**Project group**

During the execution of the project the research team included:

<table>
<thead>
<tr>
<th>Name</th>
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<tbody>
<tr>
<td>Prof. Ir. A.C.W.M. Vrouwenvelder</td>
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<tr>
<td>Dr. Ir. P.H. Waarts</td>
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<td>Dr. Ir. J.E.A. Reinders</td>
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<tr>
<td>Dr. E.E. van der Hoek</td>
<td>GeoDelft</td>
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<td>Ir. S.N. Jonkman</td>
<td>RWS-DWW</td>
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<tr>
<td>K. Heijnert</td>
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<tr>
<td>Prof. A. van der Veen</td>
<td>Twente University</td>
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<tr>
<td>Ir. L.C.P.M. Stuyt</td>
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<tr>
<td>Ir. M. de Muinck Keizer</td>
<td>Delphiro/CSO</td>
</tr>
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**Other Involved personnel**

The realisation of this report involved:

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Dr Ir J.E.A. Reinders</td>
<td>TNO</td>
</tr>
<tr>
<td>Ing. J.M. Ham</td>
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