The sinking of a double-deck floating roof on the 70-m diameter B962 tank containing over 62,200 m³ of crude oil was detected on July 18, 2007 in a refinery. No product had been transferred from this tank since July 2, the day of the most recent filling. Monitoring of the tank level had revealed abnormal variations beginning on July 5. The level of liquid in the container was read at 14 m when the sinking roof was first remarked, causing 3,850 m² of surface area of crude to enter into direct contact with the ambient air.

The facility operator logged the tank’s electrical supply and verified the hydrocarbon vapour concentration every 2 hours at the site of the retention basin. An emergency fire-fighting vehicle from the refinery’s fleet was positioned along the edge of the basin ready to intervene. A series of hydrocarbon concentration measurement sensors installed in the town of Petit-Couronne recorded very high concentration levels (between 10,000 and 25,000 µg/m³), yielding an average background noise of 1,500 µg/m³.

The Hazardous Installations Inspectorate noted these facts. The operator proceeded with a gravity transfer of tank contents into other refinery tanks until the liquid level neared that of the roof, which had stabilised at 2.8 m. The tank shell was then punctured at high pressure and water injected into the tank to enable removing the remaining hydrocarbons by means of pumping. Drainage operations continued for several weeks in order to extract via a bottom outlet all liquid contained inside the tank along with the sediments that had settled.

The operator estimated the quantity of volatile organic compounds (VOC) emitted into the atmosphere during these tank drainage and safety prevention steps at more than 3,000 tonnes, including approximately 55 tonnes of benzene.

While awaiting the final results of investigations performed at the time the roof was disassembled, the initial findings released by the operator tend to support the hypothesis of a loss of flotation capacity due to overload caused by both the accidental filling with crude of a leaky caisson and the accumulation of rainwater on the roof. The foot valve on the rainwater discharge trough had been closed, subsequent to the detection a few months prior of hydrocarbon leaks inside the discharge drain.

Renewed use of the tank following repairs has been scheduled for the end of August 2009.
Floating roof

Installed directly at the liquid surface, the floating roof of a storage tank enables reducing the evaporation losses of certain products via the vapour portion and thereby limiting the chronic atmospheric releases generated by the most volatile products. These economic and ecological advantages have contributed to the widespread development of floating roofs, in particular for storing liquids with high vapour pressure, such as some crude oils, naphthas or gasoline. Accident statistics held on floating roof tanks confirm the necessity of closely monitoring operations and maintenance, especially given their tendency to have large capacities in addition to their more sophisticated designs.

The phenomenon of roof submersion by the product contained within the tank has been observed on a considerable number of occasions (ARIA 1514, 22491). A lateral or rotating motion, excessive tilting or sticking can lead to a loss of liquid tightness between the roof deck and the tank shell significant enough to allow the liquid to submerge the roof (ARIA 22491) and in some cases cause the roof to sink (ARIA 10208, 22325). The seepage of rainwater or stored product into one or more roof caissons subsequent to a faulty seal can also produce either total (ARIA 33335) or partial (ARIA 34360) roof immersion.

The filling phases are particularly sensitive to this type of event (ARIA 10208, 22325, 22490), since the roof moves vertically in sync with the rising level inside the tank. In addition to enhanced monitoring, special attention needs to be paid to both the filling rate and effective operations of onsite prevention equipment (level alarms, speed limiters, etc.). In some instances, roof submersion is accompanied by fire whose ignition has been facilitated by the presence of vapours that become combustible when in direct contact with air (ARIA 6277, 22325).

Roof immersion in the liquid is not the only situation where a highly-inflammable vapour portion forms above the roof. Besides faulty seals at the level of the peripheral joint (ARIA 20819), corrosion-induced leaks (ARIA 34360) or cracking may appear within the roof structure itself. The vapour portion is thus capable of igniting and causing serious accidents. In 1983 in Milford Haven (ARIA 6077), the ignition of vapours escaping through cracks some thirty centimetres long localised on the membrane of a single-deck roof of a light crude tank led, by extension of the initial defect, to a tank “boilover” and the destruction of several adjacent tanks. More recently in Skikda during 2005 (ARIA 34130), the combustion caused by a vehicle of a gas cloud, which had formed above the floating roof on a crude oil tank and then gathered over a lower elevation zone, caused an enormous fire, the deaths of 2 plant technicians and tremendous outpouring by the local population. Besides installing detection devices, the effectiveness of the initial emergency response can prove determinant in containing the spread of the blaze (ARIA 27990, 6077).

Large storage tanks are exposed to an aggressive atmosphere, and many events affecting floating roofs arise during or after periods of severe climatic conditions: violent winds, in one instance fanning the flames on the floating roof of a tank in Finland containing hexane (ARIA 134), while in another contributing to crack formation in the roof structure at Milford Haven (ARIA 6077); snow causing a roof in Essex (U.K.) to sink (ARIA 22326); frost leading to the failure of a flange joint on the stormwater drain in Carling (ARIA 10331); heavy rain accumulation resulting in tilting (ARIA 32340), or in Petit-Couronne to the actual sinking of a roof (ARIA 33335) due to an inefficient stormwater discharge system. Tanks equipped with a floating roof are also vulnerable to the impact of lightning. Fire often breaks out at the level of the roof air seal (ARIA 6277, 20819, 20587) and sometimes extends throughout the tank (ARIA 27990). The quality of the shell/roof equipotential bond, grounding and the seal around the joint (ARIA 12229, 12231, 20819) all constitute efficient preventive measures for coping with this risk.

Several cases of accidental discharges of the product contained in tanks have been recorded in ARIA, and these generally stem from a defect or malfunction in the drainage system for rainwater collected on the roof. Such equipment plays a key role in the mechanism for confining the product inside the tank. A deficient seal on the stormwater drainage line causes the product to penetrate into the line (ARIA 22293, 26740), followed by product flow into the retention basin associated with the tank (ARIA 10207, 34360) or, in some cases, into a collection pipe network (ARIA 34360). Except for the case where the retention device displays a poor quality seal (ARIA 26740), the products may be recovered in the basin, and in general this type of incident does not yield serious consequences.

Regardless of the facilities involved, works performed tend to generate specific risks that would need to be analysed in order to determine the appropriate means of prevention. The potential presence of vapour on a floating roof complicates all operations carried out in the vicinity of the roof (ARIA 19534), especially in the event of incandescent projections. Even after draining and degassing the tank, any hot spot activity on a floating roof introduces a set of risks specific to the potentially inflammable nature of the atmosphere inside or immediately adjacent to a tank (ARIA 8988).

Accident analyses have revealed a wide array of scenarios leading to incidents and accidents involving floating roofs with potentially sizeable human, social, environmental or economic impacts. Such analyses underscore the need for permanent and reinforced supervision of the proper operations of all devices placed into service (roof position and absence of liquid at the surface, filling phases both during and after the occurrence of extreme climatic conditions), yet with even greater emphasis on detailed controls and strict maintenance (overall state of repair of the roof deck, efficiency of the joint and the stormwater drain, close monitoring of all works conducted).

The accidents whose references are not underlined may be consulted at: www.aria.developpement-durable.gouv.fr
The hypothesis of ignition triggered by static electricity discharge has received the most support.

**ARIA 134 - 23/03/1989 - FINLAND - PORVOO**

A hexane leak occurred above the floating roof of a 30,000-m³ tank 52 m in diameter and 14 m high. Despite application of a foam layer, ignition occurred the following day. The fire was extinguished within 50 min, but a break of the foam film caused by wind (blowing at 20 m/s) led to re-ignition after another 52 min. The second fire required 27 hr to extinguish, once the product had been transferred, necessitating the deployment of 509 rescue workers and the consumption of 200 m³ of emulsifiers. Total damage was estimated at 30 million Finnish markka. 15,000 of the 22,000 m³ of hexane contained inside the tank burned during the fire.

**ARIA 6777 - 30/08/1983 - UNITED KINGDOM - MILFORD HAVEN**

In the storage tanks of a refinery (production: 5 million tonnes/year), smoke was detected on a 94,000-m³ capacity floating roof tank containing 47,000 tonnes of light crude oil (flash point: 38°C). Shortly thereafter, the surface (4,800 m²) ignited. In the absence of a fixed protective device, the emergency response team projected foam at the tank roof using a gun mounted on an aerial platform, while protecting the adjacent tanks and cooling the walls of tank no. 11. The roof collapsed (with an estimated roof load equal to 700 tonnes). A few hours later, the requisite resources were in place: 26 pumps, 11 cisterns, 6 hydraulic platforms, and a crew of 150 fire-fighters. In conjunction with this response effort, the crude was being drawn out (at a rate of 1,700 tonnes/hr) in order to lower the tank level. A full-scale foam attack was deemed necessary, although the emulsifiers had not yet been installed; 160 m³ of the total 200 m³ were considered the minimum necessary. An emulsifier collection plan was thus launched. The rate of oil burned in the tank by fire was estimated at 300 tonnes/hr. The nearby tanks (2), which had been exposed to strong thermal radiation, had to be drained (as a result of heat insulation damage). Tank no. 11 started bubbling in its upper part and of oil burned in the tank by fire was estimated at 300 tonnes/hr. The nearby tanks (2), which had been exposed to strong thermal radiation, had to be drained (as a result of heat insulation damage). Tank no. 11 started bubbling in its upper part and

**ARIA 9988 - 30/05/1996 - 76 - LE HAVRE**

The floating roof of a 15,000-m³ storage tank containing platformate (a mixture close to that of gasoline) sank for an unknown reason. This immersion was detected on November 5 at 9:40 pm. Despite spreading the foam in an effort to prevent fire, lightning caused the product to ignite on November 7 at around 9:45 pm during a violent thunderstorm, once the foam layer had been weakened by the downpour. The fire was contained within 40 min through deploying in-house response teams. The volume of hydrocarbons destroyed in the fire was estimated at 400 m³; moreover, 25,000 litres of emulsifiers were consumed. Property damage estimates amounted to 2.2 million francs.

**ARIA 20819 - 01/01/1999 - TUNISIA - BIZERTE**

A fire broke out on two gasoline reservoirs with floating roofs. The reservoir joints were not properly sealed. During a thunderstorm, lightning ignited the gasoline vapours emanating from the leaks. The fire was controlled by rescue teams in 40 min. The reservoirs were heavily damaged, and a significant quantity of gasoline was lost (several thousand m³).

**ARIA 22325 - 26/02/1991 - UNITED KINGDOM - ESSEX**

Inside a refinery depot subsequent to mishandled supply of a tank containing 7,000 tonnes of naphtha (and perhaps also due to the weight of snowfall), the tank's floating roof became immobile and then sank. A technician sprayed foam onto the tank in order to limit evaporation of the product, but the foam was applied erroneously (as a result of inadequate training/instructions/procedures for emergency situations) in the middle of the tank surface rather than at the periphery. The static electricity charges produced then ignited naphtha/air vapours. Given the low ambient temperature (0°C), flash was not produced and the vapours ignited progressively as they were being released. The site's emergency response plan was triggered, and both internal and external rescue teams fought the fire for 3 hours before its extinction. No impacts could be observed on the environment. Following this accident, the set of communication procedures as well as instructions and training on static electricity charges underwent revision.
ARIA 22490 - 17/07/1999 - GERMANY - KARLSRUHE
20.1 - Manufacturing of basic chemicals, nitrogen products and fertilisers, basic plastics and synthetic rubbers
While making rounds at a storage tank facility, a watchman noticed a smell of crude oil. Since this observation coincided with filling a storage tank with crude, a fellow employee inspected the tank and reported that the floating roof was entirely covered by crude. The initial measure adopted was to halt the ongoing tank supply. For safety and environmental protection reasons, fire-fighters spread out a foam carpet. Hydrocarbon and H2S measurements taken immediately thereafter did not indicate any noticeable concentrations. Only a slight odour could be perceived at the site before foam was implemented throughout.

ARIA 22491 - 09/06/1999 - GERMANY - KARLSRUHE
20.1 - Manufacturing of basic chemicals, nitrogen products and fertilisers, basic plastics and synthetic rubbers
Gas discharge occurred at a storage tank facility. The subsidence on one side of a floating roof (approx. 10° incline) caused a momentary release of fumes (gasoline and thiols). In a span of 8 hours, the roof completely collapsed. Any release of gases could be avoided by application of a foam cover, and the tank was then emptied. The event was detected from the odours produced. Fire-fighters set up a wide safety perimeter, covered the foam liquid and proceeded with analyses that turned up nothing abnormal. This incident caused nausea among a few of the individuals on or near the site.

ARIA 26740 - 29/12/2003 - 67 - REICHSTETT
19.20 - Oil refining
On the hydrocarbon storage site at a refinery, a 50-m³ leak of aromatic hydrocarbons was identified on a 10,000-m³ vertical tank with a floating roof. The discovery was made by a technician during a sampling step conducted when transferring the product to a manufacturing unit. The technician stopped this flow by closing the drain valve. A portion of the hydrocarbons was held in the retention ring, while the remainder spilled out into the retention basin (presence of two stains 10 m² in surface area on the ground) and infiltrated. The hydrocarbons contained inside the ring were then pumped. The operator shut down the specific tank in the aim of completely draining and degassing it to enable additional investigations (to determine origin of the failure and the type of repairs needed). Moreover, he installed a pump operating at 40 m³/hr in a pre-existing shaft, located approx. 30 m upstream of the pollution in order to contain potential groundwater pollution. This measure was accompanied by tracking the evolution in pumped water quality. Two days later, the industrial owner noticed the first traces of hydrocarbons arriving in the collection basin of the refinery's waste treatment plant. The drain was isolated and the tank was first drained then filled with water.

Six executives working with the oil rig were sanctioned for non-compliance by senior company management, and another 6 who oxygen, the engine of the vehicle in which the 2 company employees died started up again and ignited the gas cloud, spreading normal position, had to stay open to allow for rain water to flow from the floating roof. Furthermore, the operator was responsible for identifying those tanks on the site whose equipment had been identically configured: a single tank fit this condition and was shut down while awaiting verification inspection.

ARIA 27990 - 20/06/1987 - UNITED STATES - NC
46.71 - Wholesale of fuels and accessories
In a liquid hydrocarbon storage facility, fire broke out on a floating roof tank (12-m high) containing 9,300 m³ of unleaded gasoline (filled to the ¾ level). Lightning was the cause of this accident. Since the tank had not been fitted with fire-fighting equipment, the safety team elected to fight the fire with a handheld hose from the truss atop the tank shell: the fire engulfed approx. 20% of the total circumference yet could not be contained by fire-fighters at the site, who were forced to withdraw. The fire spread over the entire roof, which ultimately sank; the tank was destroyed and damage was estimated at USD 10 million.

ARIA 34130 - 04/10/2005 - ALGERIA - SKIKDA
19.20 - Oil refining
An explosion followed by a fire occurred around 10:00 am on a tank with a nominal capacity of 51,000 m³ containing 35,000 m³ of crude in an oil terminal; the fire quickly spread to an adjacent tank. The inflamed crude then generated a tremendous blackish cloud over 200 m high standing above the petrochemical operations platform and the neighboring city. The automatic tank extinction system malfunctioned and emergency team organisation and coordination problems complicated the task at hand: 5 fire-fighting vehicles parked too close to the first tank caught on fire and were totally destroyed by the flames. No measures were adopted to ensure the safety of the nearby population, many of whom panicked and fled the town. It took 8 days for the fire to be fully contained. The human toll was a heavy one: 2 deaths and 7 injured, with financial losses assessed between 5 and 6 million dollars.

According to the conclusions drawn from the investigations conducted, inflammable gases would have formed above the tank's floating roof and accumulated at a lower elevation where an internal access path ran. After having stalled due to a lack of oxygen, the engine of the vehicle in which the 2 company employees died started up again and ignited the gas cloud, spreading flames towards the top of the tank. Six executives working with the oil rig were sanctioned for non-compliance by senior company management, and another 6 who participated in demonstrations held by the local population were fined and convicted with a suspended sentence.

ARIA 34360 - 17/01/2008 - 13 - MARTIGUES
19.20 - Oil refining
Around 11:00 am, the arrival of a major delivery of liquid hydrocarbons was recorded at the preliminary sedimentation basin of the refinery's waste treatment plant. A technician noted the presence of product on the floating roof of tank CU15 containing "FCC gasoline", with a gravity runoff system passing via the stormwater collection drain on the roof in the direction of the oily water collection network. The drain was isolated and the tank was first drained then filled with water.

The personnel present near the treatment plant were evacuated from the site's basin zone as a precautionary measure due to strong hydrocarbon odours, while measurements of both COV and benzene content in the atmosphere were conducted: results proved to be negative. After cleaning, the plant and collection basin were placed back into service. The quantity of FCC gasoline released was calculated at 40 m³. The operator had identified external corrosion on the upper shell of the double-deck floating roof. Rainwater had infiltrated into the central caisson and subsequently overflowed into two other caissons. The roof tilted and wound up being partially submerged (less than 10% of its surface area).

The operator has been studying the possibility of installing a hydrocarbon detector on the basin's oily water drain in order to prevent any accidental inflow of hydrocarbons into the treatment plant.