

CONSEQUENCE MODELLING OF THE HYDROCARBON FIRE AT LONGFORD, AUSTRALIA, 25 SEPTEMBER 1998

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On 25 September 1998, the Esso gas processing and crude oil stabilisation plant at Longford, Victoria, Australia, suffered a loss of containment on a reboiler for a rich oil demethaniser. The release of hydrocarbon formed a vapour cloud, which subsequently ignited. The fire caused 2 fatalities and 8 injuries, and led to a series of escalating fires and explosions. The plant was shut down, causing massive disruption to gas supplies throughout Victoria for 2 weeks. The paper describes a mathematical model of the progression of the accident, prepared by DNV as part of the investigation by the Longford Royal Commission. The model covers the nature of the hydrocarbon, the rate of release, its dispersion through the plant, the ignition, and the subsequent fire and escalation. The model used the consequence assessment program PHAST, with necessary parameters derived from ambient data and tuned to match available evidence from the witnesses to the accident. The paper describes the treatment of uncertainties about many of the input parameters, and shows that the model gave good agreement with nearly all the witness observations. The combination of witness evidence with consequence modelling allows a better understanding of the full course of events than either would alone.

Keywords: accident, fire, hydrocarbon release, consequence modelling

INTRODUCTION

BACKGROUND

On 25 September 1998, the Esso gas processing and crude oil stabilisation plant at Longford, Victoria, Australia, suffered a hydrocarbon release that ignited, causing 2 fatalities and 8 injuries, and led to a series of escalating fires and explosions. The plant was shut down, causing massive disruption to gas supplies throughout Victoria.

As part of its investigation into the accident, the Longford Royal Commission asked Det Norske Veritas (DNV) to model the consequences of the release, and determine whether the prevailing understanding of the causes of the accident was consistent with the fires and explosions that were observed. The Commission's report[1] concentrates on the witness evidence and the deduced causes of the accident. The present paper describes some of the consequence modelling work that was undertaken to support the investigation. It illustrates the difficulties of matching even well-validated consequence modelling tools to real events.

GENERAL APPROACH

DNV's general approach was to try to interpret the evidence from the witnesses using, as far as possible, standard consequence modelling techniques. For this purpose, DNV's PHAST model is used, since it is widely used in the chemical process industry, and has shown good agreement with experimental results in validation exercises[2].

PHAST, like other similar computer codes, models open space consequences rather than the specific geometry of an individual situation that may apply in an accident investigation. PHAST is deliberately conservative in cases where modelling is uncertain, i.e. tending to err on the side of over-predicting the consequences. This means that, when modelling the development in time of a specific event, PHAST may indicate faster and larger development than would occur in reality. This should be borne in mind when comparing its predictions with witness evidence of the Longford accident.

THE PLANT

The accident occurred in Gas Plant 1 (GP1) of the Longford facility. GP1 was a refrigerated lean oil absorption plant, designed to separate methane from the other hydrocarbon components in natural gas. GP1 was commissioned in 1969, and subsequent plants GP2 and GP3 at the facility used a newer cryogenic separation process, rather than absorption oil.

Figure 1 gives a simplified overview of the process in GP1. Lean oil (a light oil similar to kerosene) was passed through absorbers to absorb hydrocarbons (mainly ethane and propane) from natural gas, being then known as rich oil. Using a rich oil demethaniser (ROD) and other equipment, the hydrocarbons were released yielding lean oil, which was continuously recirculated.

THE RELEASE

THE RELEASE SOURCE

The vessel that failed was a heat exchanger (GP905), known as a demethaniser reboiler because it heated rich oil at the bottom of the ROD column. As shown in Figure 2, the rich oil flowed through the tubes and then back to the ROD. The source of the heat was hot lean oil that flowed through the shell side.

On 25 September, lean oil circulation was lost due to a process upset, and the operators were unable to restart it for some hours. During this time, it appears that cold condensate from the absorbers entered the ROD and GP905, chilling them to about -48°C, far below their normal operating conditions. The Commission concluded that GP905 failed catastrophically due to brittle fracture, probably due to the introduction of hot lean oil while trying to restart circulation.

WITNESS OBSERVATIONS

Several people were in the area of the release, as they were trying to clean up a small leak from another heat exchanger, GP922, located immediately beside GP905. They gave remarkable descriptions of the event:

- Mr Shepard: “A boom and a loud violent release. I have a mental picture of the 905 eastern end being elevated and a white release…. I was on my hands and knees totally surrounded by white hydrocarbon vapour”. He was sprayed by gravel raised by the release, and received burns from what appeared to be hot lean oil. He crawled into the control room (about 20 m away) before the ignition.
- Mr Foster: “A loud thundering noise… There was a white vapour cloud all around me obscuring my vision of the surroundings.” He fell under GP922 and crawled out of the cloud to the control room before the ignition.

Although most witnesses described the initial release as a loud noise, some called it an “explosion”. Given the absence of blast damage on the plant, and the subsequent observations of a vapour cloud, it appears that these comments refer to the pressure burst associated with the sudden loss of containment on GP905.

MATERIAL RELEASED

Since the plant was not in its normal operating conditions, the composition, pressure and temperature of the release are uncertain. In normal operation, GP905 would contain rich oil at 28 barg and 176°C. The investigation indicated that the material in GP905 at the time of the failure was condensate. Available estimates of the conditions inside GP905 at the time of failure were:

Pressure	24 barg	(possible range 22 to 28 bar g)
Temperature	-45°C	(possibly as low as -65°C)

The material composition is very uncertain. Table 1 shows typical compositions for rich oil and absorber condensate, and an estimated composition for condensate in the ROD bottom with some of the methane flashed off in the above conditions. In the consequence modelling, the ROD condensate was used as the best estimate of the release composition, while the rich oil and absorber condensate compositions were used as sensitivity tests.

The physical properties of the ROD condensate were estimated by PHAST as shown in Table 2. When modelling the release and dispersion, PHAST uses a pure component with these properties.

RELEASE PATHS

The forensic investigation of GP905 revealed a major fracture of the tube channel, which unzipped almost instantaneously (Figure 3). It did not involve any leak from the shell side. The fracture opened two leak paths:

- Back flow through the GP905 rich oil outlet pipe from the ROD.
- Forward flow through the GP905 tubes, and the rich oil inlet pipe from the ROD.

RELEASE STAGES

The release rate would be very high at first, due to the high pressure of the liquid in GP905, but would quickly reduce as the ROD and associated equipment depressurised. The time-history of the flow rate (and ultimately the size of the resulting fire) would depend on the depressurisation characteristics of the GP1 system. No detailed model of this was available, and the following discussion is necessarily speculative.

Table 1 Material Compositions

COMPONENT	FORMULA	RICH OIL % mol	ABSORBER CONDENSATE % mol	ROD CONDENSATE % mol
Methane	CH_4	-	54%	18%
Ethane	C_2H_6	24%	21%	38%
Propane	C_3H_8	40%	14%	25%
iso-Butane	C_4H_{10}	4%	3%	5%
n-Butane	C_4H_{10}	3%	3%	5%
Other hydrocarbons	C_5+	29%	2%	4%
Carbon dioxide	CO_2	-	3%	5%

Table 2 Physical Properties of ROD Condensate

PROPERTY	CONDENSATE AT RELEASE CONDITIONS (-45°C 228K)	CONDENSATE AT AMBIENT CONDITIONS (13°C 286K)
Liquid density (kg/m^3)	482	413
Vapour density at 1 bara (kg/m^3)	1.98	1.57
Vapour density at 25 bara (kg/m^3)	515	65
Vapour pressure (bara)	22.4	57.9
Lower flammable limit (% vol)	2.6	
Upper flammable limit (% vol)	12	

Table 3 Estimated Release Rate Profile

STAGE	FLOW RATE (kg/s)	DURATION	RELEASE (kg)	MATERIAL
1. GP 905 outlet channel	-	-	125	Condensate
2. Liquid from GP905 and ROD bottom	2700 (1400-6000)	4 sec (2-5 sec)	10,000	Condensate
3a. Liquid from feed and reflux before ESD	7.5 (6-30)	2 min	900	Lean oil + 40% condensate
3b. Liquid from feed and reflux after ESD	5	23 min (2 to 60)	6,800	Lean oil + 10% condensate
4. Vapour from absorbers	3 (1-10)	22 min (20-120)	4,000	Vapour
TOTAL			22,000	

The following main stages of the release are distinguished:

1. Initial instantaneous release of the liquid in the GP905 outlet channel. This was negligible compared to the ensuing flow.
2. Early release of the liquid in GP905 tube side and the ROD bottoms. The initial release rates in the two flow paths were estimated using the PHAST model for a liquid release through a rupture of a pipe from a vessel at 24 barg.
3. Subsequent release of the liquid feeding into the ROD prior to isolation. This flow was estimated using available level and flow recordings of the inflow to the ROD through each possible supply route. These showed a reduction in the feed to the ROD after 2 minutes, possibly due to ESD, although reflux flow appeared not to change, and dominated the results
4. Progressive release of the vapour and flashing liquid from the attached equipment once isolated. No model was available of this, and simple estimates were made.

The overall estimated release rate profile from GP905 is given in Table 3. This is based on many assumptions and simplifications, and the estimates are very uncertain. Selected uncertainty ranges are included, based on different assumptions, showing the very different results that might be achieved.

In reality, a smooth transition would occur, with high initial flow rate decaying exponentially to zero and the different release stages overlapping. However, in the absence of a realistic model of this effect, the simple model above gives a reasonable first estimate and illustrates the rapid variation in flow rate with time. It is simply summarised in the Commission's report[1] as an initial release of at least 10 tonnes and an ultimate release of 20 to 25 tonnes.

CLOUD DISPERSION

WITNESS EVIDENCE

The extent of the vapour cloud at the point of ignition is reasonably well established from the area in which weeds in the gravel were burned. This was an ellipse, 170 m long x 55 m wide (Figure 4).

Observation of the height of the top of a moving, developing, dense vapour cloud is inevitably imprecise. One observer, Mr Rawson, reported that it was as high as the pipe racks, i.e. 4 to 6 m. Another, Mr Cumming reported that the cloud was half way up the ROD tower, i.e. 18 m.

Several observations indicate how much time elapsed between the initial release and the ignition. Mr Shepard and Mr Foster crawled a distance of about 20 m before the ignition, which might have taken less than a minute. Mr Hector and Mr Vandersteen, who were further away, describe two explosions (assumed to be the initial release followed by the ignition) with a period of 1 to 2 minutes between them. Mr Cumming also heard two noises, which he thought were a few seconds apart, but then ran from the canteen to the control room and made various attempts to combat the vapour cloud before he reported the ignition, which would have required several minutes. Mr Jackson ran the same distance but did not describe any further time before ignition. Mr Rawson made a radio call and rode his bicycle a distance of 50 to 80 m before the ignition, which may only have required about a minute. Overall, a time of 1 to 2 minutes seems most likely.

RELEASE GEOMETRY

Forensic evidence showed the bottom of the channel barrel peeled back and the end plate blown off (Figure 3). This would have allowed the flow from the rich oil outlet pipe to be orientated downwards, and the flow from the tubes to be orientated east. A confused flow would have resulted, with the main flow downward towards the ground.

The end of GP905 was lifted to approximately 2 m off the ground in the accident. The height of the release point was therefore modelled as 2 m above the ground.

No standard models of this type of release geometry exist. PHAST allows a downward jet in the input, but redefines this internally as a horizontal release 1 m off the ground pointing in the same direction as the wind. It reduces the estimated velocity by a factor of 4 to simulate the effect of the momentum reduction in a downwards release. This approach was adopted here.

BASE CASE DISPERSION RESULTS

The dispersion results were dominated by the initial liquid release of 2700 kg/s for 4 seconds. In effect, this is an instantaneous release, although PHAST allows it to be modelled as a pipe rupture, and then calculates its quasi-instantaneous behaviour. Using default modelling and the parameters defined above gave the following key results:

- Rain out of 22% of the release, i.e. 2200 kg, to form a pool on the ground.
- Remaining vapour cloud is roughly circular in plan, spreading laterally while drifting down-wind. During this process, the cloud mixes with air at the edges, progressively diluting it.
- Subsequent evaporation of the pool forms a smaller vapour plume extending back to the pool.

PHAST represents the combined cloud as a plume, extending downwind of the release point. Figure 5 shows the overall cloud footprint when fully-developed, i.e. assuming steady state conditions. This shows an overall length for the flammable cloud of 850 m, and a maximum width 700 m. In reality, the cloud did not become this large, as the maximum extent of the burn area was only 170 m from the release point. The implication from these results is that it was ignited before it reached its maximum extent, although built-in conservatism in the PHAST modelling will account for some of the difference.

The cloud shape at the intermediate stage of development, when the cloud front reached 170 m, is approximated by the 25% (molar) concentration envelope, which is included in Figure 5.

Table 4 summarises some key cloud parameters for this case. It should be noted that the height and width of the partly developed clouds are very uncertain, as the version of the program (v5.22) was not optimised to produce them.

Table 4 Base Case Dispersion Results

TIME	DISTANCE DOWNWIND (m)	WIDTH (m)	HEIGHT (m)	CENTRELINE CONCENTRATION (%)
After 26 sec	170	78	4	25
After 1 minute	250	160	5	18
After 2 minutes	400	300	8	10
After 5 minutes	850	700	16	2.6 (LFL)

COMPARISON WITH WITNESS EVIDENCE

Comparison with witness evidence is possible as follows:

- The predicted pool on the ground of 2200 kg is not supported by evidence from Mr Shepard and Mr Foster, who were within the release and did not report any liquid. It is likely that the turbulence of the release impinging on the ground atomised any liquid, preventing it raining out. This was investigated by sensitivity tests.
- The predicted flammable cloud shape up to 170 m is largely conical, whereas the burn area was an ellipse. This type of discrepancy is an inevitable result of the underlying assumptions in consequence modelling. For example, PHAST assumes a unidirectional release, which makes the cloud relatively narrow near the source. PHAST does not explicitly model the turbulence from the process equipment, and in reality the dispersion through process equipment would have produced a broader cloud. Allowing for these simplifications, the agreement between the modelled and observed clouds is relatively good.
- The predictions suggest that the 170 m long burn area would have been reached in about 26 seconds. This does not match the ignition time of 1 to 2 minutes estimated from the witnesses. This may be due to conservatism in the way PHAST assumes the release is oriented downwind. However, this apparent discrepancy can also be reconciled within the flash fire modelling (see below).
- The predictions suggest that the cloud concentration at 170 m would have been 25% on the centreline. This is above the upper flammable limit. However, flammable concentrations would have existed on the edge of the cloud. The witness observations that indicate a rich cloud when ignited tend to support this (see below).
- The predictions give a height of 4 m for the flammable cloud when it is 170 m long. This agrees with the evidence from Mr Rawson. It is lower than estimated by Mr Cumming, who compared it to the height of the ROD. The cloud height at the ROD may have been greater due to the barrier effects of the process equipment, pipes and pipe racks.
- The predictions suggest that the overall travel distance of the flammable cloud, if it had not ignited, would have been much greater than the 170 m observed extent - approximately 850 m in a flat, unobstructed field. If the maximum travel distance were to be only 170 m, this would have required much greater turbulence around the equipment than in the standard turbulence profile or a reduced release momentum.

SENSITIVITY TESTS

Several sensitivity cases were modelled:

- Reduced droplet size, ensuring no rainout.
- Wind speed reduced from 3 m/s (measured at the nearest official meteorological station) to 0.3 m/s (measured at the plant).
- Atmospheric stability changed from B/C to A, consistent with lower wind speed and strong sunlight.

- Discharge velocity reduction factor changed from 4 to 10.
- Flashing liquid release changed to vapour release.
- ROD condensate changed to absorber condensate.
- ROD condensate changed to rich oil.

Table 5 Confidence Ranges for Key Dispersion Results

PARAMETER	BEST ESTIMATE	CONFIDENCE RANGE
Rain out fraction	22%	0 to 80%
Time to reach 170 m	26 sec	10 to 50 sec
Flammable cloud width when front reaches 170 m	78 m	60 to 220 m
Flammable cloud height when front reaches 170 m	4 m	2 to 18 m
Centreline concentration when front reaches 170 m	25% mol	14 to 38%
Ultimate extent of flammable cloud if not ignited	850 m	240 to 990 m

None of the sensitivity tests gave better agreement with the witness evidence overall than the base case, although some were better in some respects and worse in others. It was concluded that the standard dispersion model provided the best single representation of the release. The sensitivity tests were used to establish confidence ranges for the key dispersion results, as shown in Table 5.

IGNITION AND INITIAL FIRE

WITNESS EVIDENCE

Several witnesses had a good view of the ignition and the initial fire prior to escalations in the pipe racks:

- Mr Cumming (at monitor near control room, 40 m away): “I heard a whoof and saw orange flames just in the location of the eastern end of the two exchangers and up into the overhead pipe rack.” He moved to very close to the fire with a fire extinguisher: “I was standing at the eastern end of the 922 and 905 spraying at the ground fire below the 905 sweeping in an arc. There were pools of liquid in the stones which were on fire below the 905 and the 922. There was a large orange flame coming out of the 905 west (sic) end and extending up into the east/west pipe rack.” He then went into the control room.
- Mr Miller (at the control room north door, 40 m away): “There was a very loud explosion outside. I then went out the north door and saw a huge fireball in the area of the GP905 and GP922 heat exchangers”.
- Mr Noble (between the guard house and the control room): “The initial flames were a red and orange colour that indicates a heavy fuel…. They were approximately half the tower height and were increasing. The width of the base of the fire was about half the size of the fans and was increasing. I didn’t observe any fire on the ground but it was from about the height of the cowls on the fans and upwards…. There was debris falling in the general area, parts of cladding etc, and a lot of smoke rising.”
- Mr Kristeff (in the fire shed, 140 m away, before the fire truck was deployed): “The fire was not burning as high as the pipe rack…. The fire was burning predominantly from off the ground. There were no flames up the side of the tower at this time”. He indicated about a 5 m diameter area centred on GP905. He then deployed the fire

truck to 40 m away: “The fire was burning around the 922 and 905 vessels and looked to be spreading on the liquid on the ground. The fire was still low in height.”

- Mr Watson (in canteen): “I heard an explosion…. I felt the building shudder. It was a very loud bang.” He walked outside: “I could see grey/black smoke emanating from the ROD area east of the GP1 control room. The smoke was like a funnel that balled up at the top. It extended about half way up the ROD tower.”
- Mr Rawson (at junction of South Road and Control Room Road, 260 m away): “There was a very clean flame as high as the pipe rack in a ball-like configuration moving back to the gas release site. It was moving very quickly.” A few moments later: “I saw an explosion. It was just a red angry black colour. It was half as high as the ROD tower.”

The forensic investigation concluded that the fired heaters, 170 m south of GP905, were the source of ignition.

INTERPRETATION OF WITNESS EVIDENCE

Several witnesses heard an explosion, although the lack of blast damage on the plant suggests that any flame acceleration was localised. Mr Cumming was close to the cloud and heard it as a “whoof” rather than an explosion. A few witnesses saw a flame passing through the cloud characteristic of a flash fire. Mr Rawson also described an explosion a few moments later, which might have been a fireball-like combustion of the “rich” part of the gas cloud. Although in reality flash fires and vapour cloud explosions form part of a continuum of possible combustion events, for modelling purposes this event is treated as a flash fire.

Theoretical models suggest that in flashing release of condensate, some rain-out of entrained liquid might be expected. Had the release been rich oil, a liquid pool on the ground would be expected. No-one observed this prior to the ignition, and even Mr Shepard and Mr Foster, who were within the cloud, did not describe any liquid pool. After the ignition Mr Cumming described a pool fire which he tried to extinguish. However, Mr Noble did not see this, although he did suggest that the flames were characteristic of a heavy fuel. Mr Kristeff saw the fire as “burning predominantly from off the ground”, which suggests a gas jet fire rather than a pool fire, but later stated that the fire was spreading on the liquid on the ground. There are several possible explanations for this apparent conflict. The release might have been predominantly vapour with a small liquid component. The liquid content might have varied during the release. Alternatively, a vapour release might have ignited a pool fire in residue of the liquid previously spilled from GP922. Overall, a small liquid pool seems to have been present for at least part of the release.

FLASH FIRE MODELLING

After ignition, the flame front would be expected to move back through the cloud to the release point. This was clearly observed by Mr Rawson. In order to estimate the time this might take, it is noted that experimental results for LPG and LNG vapour show flame speeds relative to the undisturbed gas approximately twice the wind speed[3]. Hence, the flame speed relative to the ground while propagating upwind through a plume might be approximately equal to the wind speed.

In this case, the wind speed at 10 m elevation is estimated as 3 m/s, and the wind speed closer to the ground is estimated as 2 m/s. Although flame acceleration would occur around process equipment, the speed would reduce in more open areas, so the average speed might be relatively low even at the Longford facility.

People close to the source might not be aware of the fire until it reached them, since unburned gases in front of the flame might hide it. By the time they saw it, most of the flash fire would be over. This may explain why Mr Cumming, who was close to GP905 when the release ignited, and whose observations were very detailed, described the actual ignition in very modest terms as "a whoof". Hence, their observations of the ignition might correspond to the final stages of the flash fire rather than the initiation of it.

The relatively slow flame speed in a flash fire suggests a way of reconciling the PHAST prediction of 26 seconds to reach the ignition source with the witness evidence of a 1 to 2 minute delay until ignition. For example, if the flame speed were 2 m/s, there would be a delay of 85 seconds between ignition at the cloud front and the flame reaching the source where most of the witnesses were. Combined with a time of 26 seconds to reach the ignition source, this would give a total time for the fire to reach the source of almost 2 minutes.

The height of a flash fire depends on the gas concentration in the cloud. For concentrations at or below stoichiometric, the height would be similar to the height of the cloud[4]. This would be expected to occur at the leading edge of the cloud. This matches the observations of Mr Rawson, who was in a position to see the cloud front, and observed both the vapour cloud and the clean flame to be as high as the pipe racks.

The PHAST dispersion model predicts that, at the time of ignition, the concentration in most of the cloud would be far above stoichiometric. Combustion in this region would only occur at the edge of the cloud, forming a darker flame whose height would be much greater than the cloud height. This also matches the observations of Mr Rawson, who observed "an explosion…. a red angry black colour" half as high as the ROD tower, i.e. 18 m, shortly after he had observed the clean flame. Mr Noble also saw something very similar at this stage.

The final stages of the flash fire would probably resemble a fireball, as the remaining fuel rose under thermal buoyancy. This matches several observations. Mr Watson described smoke "like a funnel that balled up at the top", which is very similar to the final stages of a fireball.

IMPACT ON PEOPLE

There were 6 people within about 5 m of the initial release, 4 of whom survived. Two of them (Mr Shepard and Mr Foster) reported being within the gas cloud but crawling out prior to ignition. It is assumed that Mr Wheeler did the same. Mr Brew was found approximately 15 m from the release after the ignition with severe burns, and is presumed to have been within the flash fire but survived. It is assumed that the two people who died (Mr Lowery and Mr Wilson) were within the flash fire. Fortunately, no-one else was within the downwind cloud envelope.

This suggests that there were 6 people within the vapour cloud, 3 or 4 people within the flash fire, and 2 fatalities.

SUBSEQUENT FIRE AND ESCALATION

WITNESS EVIDENCE

The following descriptions concern the subsequent fire from the time when escalations occurred in the pipe racks. It was difficult to establish their time sequence:

- Mr Ward (at the control room south door): "What looked like the GP922 exchanger was well and truly alight. There were cylinders exploding across the walkway from GP922. There was cladding peeling off the analyser huts. Insulation was falling out of the pipe rack…. I started to inhale acrid fumes which weren't visible and they hurt my throat and lungs and made it difficult to breathe". He then closed the control room door. By the time control room had virtually been evacuated, the bricks inside "were warm to touch and radiating heat".

- Mr Cumming (at monitor near control room, 40 m away, before the fire truck arrived): "There was some bangs from in the pipe rack. Some of the smaller pipes had ruptured and they were adding to the fire in the pipe rack."
- Mr Kristeff (at the fire truck 40 m away): "There was another explosion that increased the size of the fire around the fin fan area". He indicated an area 14 m diameter. "The fire was now higher than the pipe rack…. There were continuing explosions and the fire was getting bigger…. The radiant heat was very hot…. There were fires at the top of the towers…. I recall there being at least 6 explosions. Each time after an explosion, the fire got bigger and eventually spread into the pipe rack." He indicated an area about 20 m in diameter. The fire crew then withdrew to the front gate.

The plant video was repositioned to observe the fire at 12:41, approximately 16 minutes after the start of the release. It first showed a red-yellow flame 15 to 20 m high, with thick black smoke rising and drifting south-east. At 13:00, a fireball 40 m wide and at least 70 m high erupted due to rupture of one of the large pipes in the pipe rack near to GP905. Further major releases occurred at 13:22 and 13:32, the latter producing a fireball 55 m wide and over 100 m high. By 14:25, isolation of the pipe racks began to take effect, and the fire was reduced to 10 to 15 m high. Final isolation and extinguishing of the fire was not completed until 27 September.

Most of the damage to the plant was within a 20 m radius of the pipe rack crossing close to GP905. Most of the pipes in the crossing were severely damaged, and in many cases broken.

GROUND FIRE MODELLING

By the time the fire reached the release source, approximately 2 minutes after the start of the release, the release rate model predicts that the material then being released consisted of lean oil mixed with up to 40% condensate. The condensate would flash to vapour, probably inside the ROD, and some or all of the lean oil would be entrained in it as a 2-phase mixture.

The release was directed towards the ground, and this would probably reduce the velocity enough for much of the lean oil to rain out, creating liquid on the ground. This would add to the more volatile liquid that rained out of the initial release of condensate. It would probably fill the crater and mix with the gravel around the release point.

Ignition of such a 2-phase release in the open would normally produce a jet fire, i.e. a torch flame, with most of the liquid burning as an atomised spray within it. In this case, with the jet impinging on the ground, there would be a confused fire, with a burning jet combined with a fire on the surface of liquid on the ground. In the later stages of the release, predicted to involve only vapour, the liquid component might not be present.

No witnesses observed such a flame, although Mr Noble described a tall flame with a narrow base. Most who described the shape called it a fireball. The probable reason for this is that impingement on the ground would have resulted in a confused flame shape, which might be roughly spherical. Since the fuel emerged continuously near to the ground, a "fireball" is not the correct technical term for this. In the absence of a standard term, this paper uses the term "ground fire", meaning the combustion of a liquid and gas jet impinging on the ground. The high-speed jet flows down and strikes the ground, spreading out sideways. At much reduced velocity, the flames burn upwards from the ground.

Table 6 Ground Fire Sizes

STAGE/MATERIAL	FLOW RATE (kg/s)	BURNING RATE (kg/m^2s)	FLAME DIAMETER (m)	FLAME HEIGHT (m)
3a. Lean oil + 40% condensate	7.6	0.08	11	21
3b. Lean oil + 10% condensate	4.9	0.065	10	18
4. Condensate vapour	3	0.11	6	17

Using the pool fire model in PHAST for ROD condensate gives the estimates of the ground fire sizes shown in Table 6. The flame heights are within the ranges observed on the plant video.

ESCALATION

The time to failure of a pipe under fire impingement depends principally on its internal pressure, the type of fluid in the pipe, the fluid flow (whether flowing or shut-in), design and ultimate hoop stresses in the pipe, and the thermal emissive power of the flame. When a flame impinges directly on a shut-in pipe, failure may occur within a few minutes, whereas pipes just outside the flame may survive for an hour or more. Failure of shut-in pipework in pool fires is typically assumed to require impingement for approximately 10 minutes, with a range of uncertainty of 4 to 60 minutes[5].

At the Longford facility, the fire must have remained large enough to cause failure of pipes in the pipe racks. The pipe racks were 4 to 6 m high, so the fire 10 minutes after ignition must have been at least this high. All the sensitivity tests considered would have met this criterion, and hence would have been sufficient to initiate a sequence of failures in the pipe racks.

CONCLUSIONS

This paper has reviewed the evidence from the witness statements about the consequences of the leak from the GP905 heat exchanger at the Longford facility on 25 September 1998, and used this as the basis for a theoretical model of the event.

While this paper has emphasised the comparison with theoretical modelling, it should be noted that witness observations and forensic evidence provide the authoritative record of what occurred in the accident. Theoretical models inevitably involve extreme simplifications of the actual events, and it may be surprising that there is any agreement between the two. However, the high degree of uncertainty about the prevailing conditions and the nature of the material released allowed the model to be tuned to match the witness evidence. The resulting model gives good agreement with nearly all the witness observations and gives a reasonable representation of the accident development, up to the point where escalations began in the pipe racks.

The combination of witness evidence and theoretical modelling allows a better understanding of the full course of events than either would alone. It helps resolve apparent contradictions between observations by showing that they consist of “snapshots”, each of which is probably an accurate record of the appearance of a rapidly changing sequence of events from a particular point at a particular moment in time.

The exercise of representing this accident using standard consequence models also raises several issues about the modelling of risks in conventional quantitative risk assessment (QRA):

- The initial leak was in effect a full-bore rupture of the tube side of a shell & tube heat exchanger, an event not commonly modelled in a QRA. However, rupture of the connecting pipe would have had similar effects to the rupture of the heat exchanger.

- The process upset that caused the failure of the heat exchanger also resulted in the released fluid being entirely different to the one normally in this equipment, and at a much lower temperature. A conventional QRA would attempt to model the normal process fluid quite accurately, and would not normally model other fluids.
- Indirectly, the process upset also resulted in several people being in the vicinity of the release, since they were attempting to repair another leak with the same cause. A QRA would normally model an average distribution of people, and not cluster them preferentially around the source of the failure.
- The release rate changed rapidly with time. In effect the release, although nominally a full-bore failure, was a massive instantaneous release followed by a small continuous release. The former determined the ignition and immediate injury probability. The latter determined the escalation probability.
- The ultimate effect of the release was determined mainly by the importance of the pipe runs close to the release source for the continued operation of the plant, and the difficulty of isolating them.

ACKNOWLEDGEMENT
This paper is published with the permission of Det Norske Veritas. It is based on evidence collected by the Longford Royal Commission and on DNV’s analysis of this evidence submitted to the Commission as part of the public record. Opinions expressed are those of the authors, and not necessarily shared by DNV.

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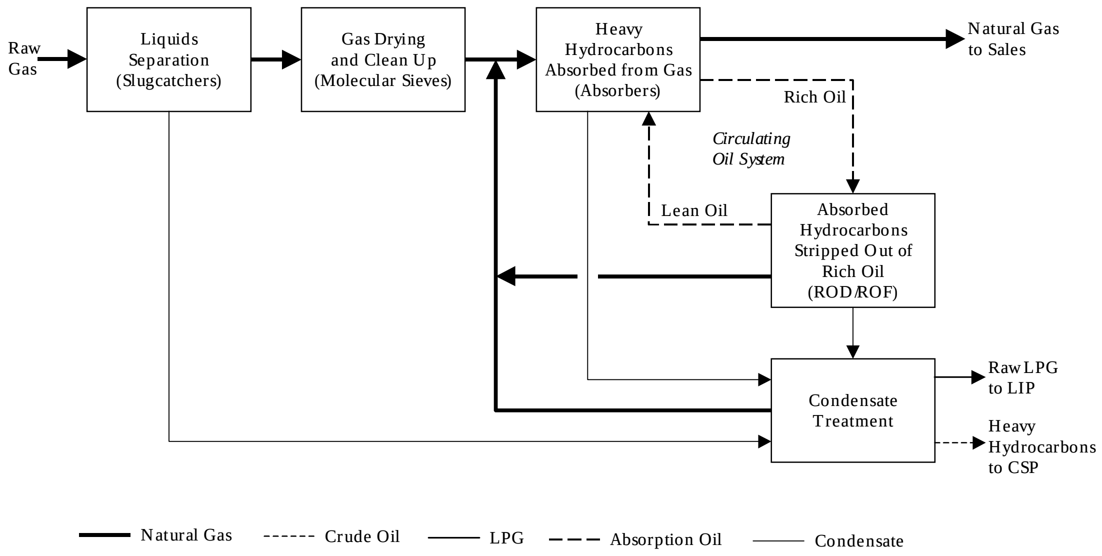

Figure 1 Simplified Overview of GP1 Process[1]

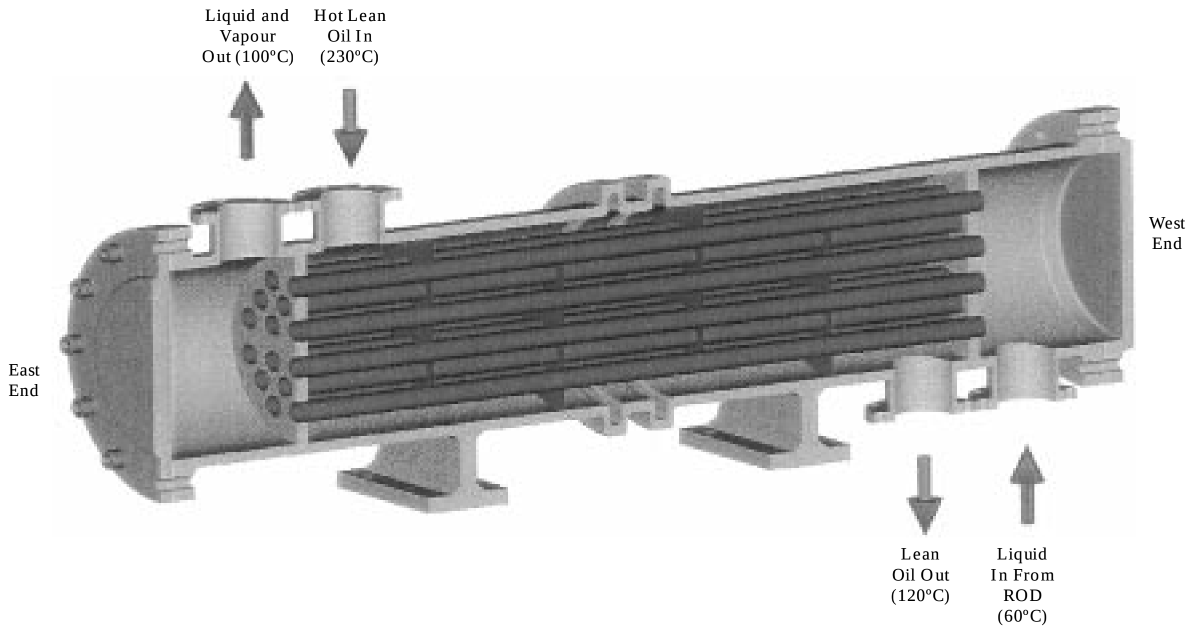

Figure 2 Schematic View of GP905[1]

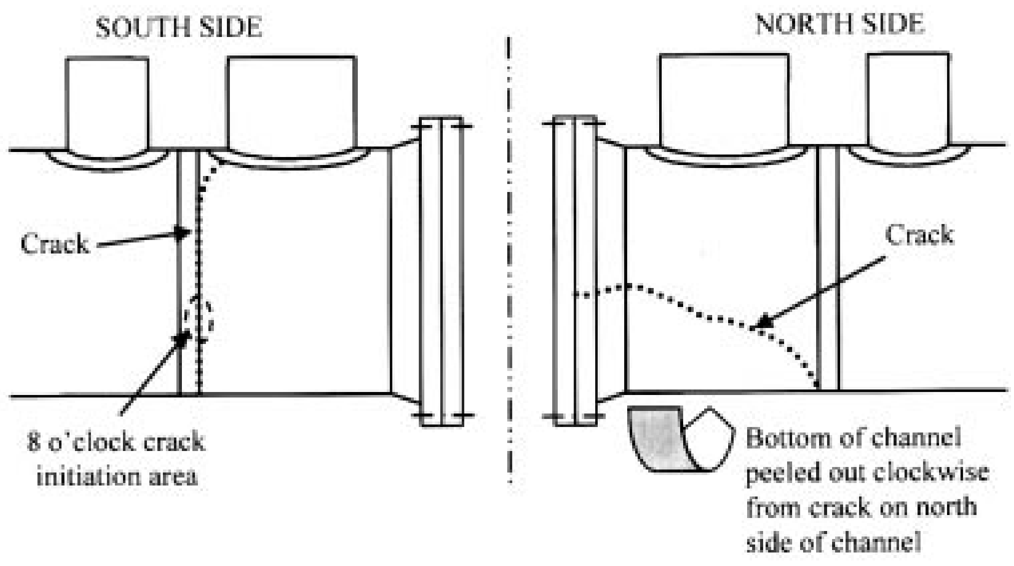

Figure 3 Schematic Representation of the Failure[1]

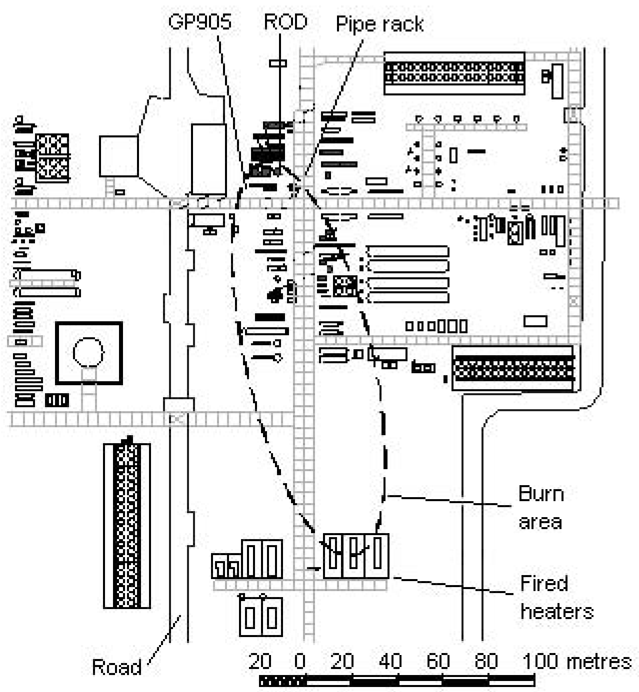

Figure 4 Approximate Plot of Observed Burn Area

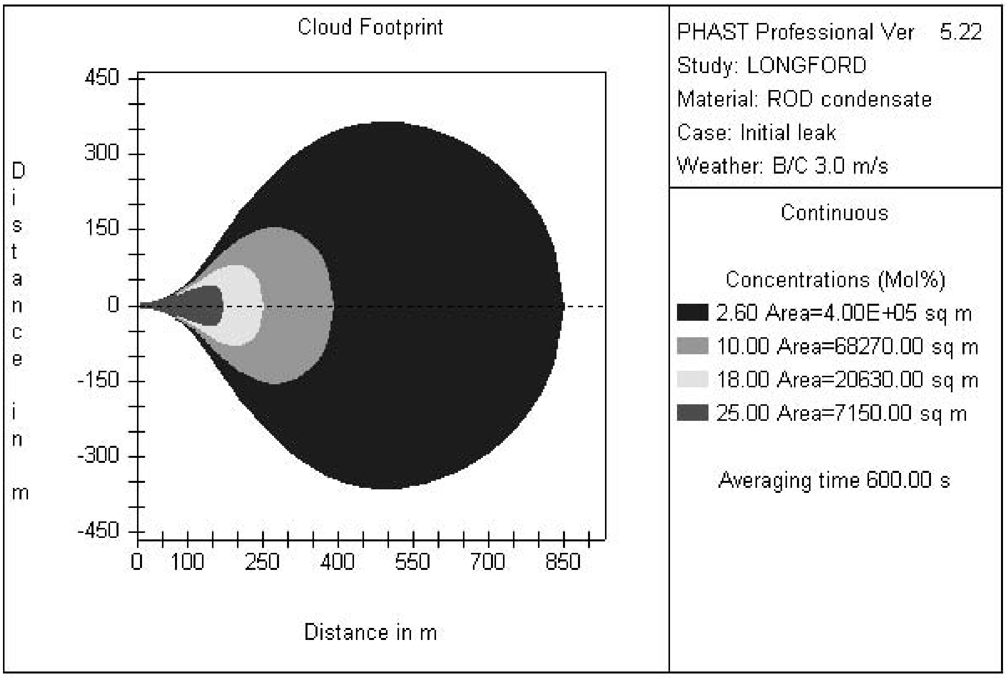

Figure 5 Footprint of Base Case Fully-Developed Cloud