Review of Gasoline Pipelines Quantified Risk Assessments

November 2003

This review has been carried out to consider Land Use Planning zones for gasoline pipelines in preparation for a meeting on 25 November 2003. Five assessments have been reviewed, of which three are directly relevant to Individual Risk transects adjacent to gasoline pipelines.

PADHI (Planning Advice for Developments near Hazardous Installations) guide requires specification of 3 planning zones adjacent to Major Hazards Installations to assist Planning Authorities to make decisions on planning applications:-

Inner Zone (Individual Risk greater than 10^{-5} per year)
Middle Zone (Individual Risk between 10^{-5} and 10^{-6} per year)
Outer Zone (Individual Risk between 10^{-6} and 3×10^{-7} per year)

Gasoline pipelines have not so far been classified as Major Hazard Pipelines and do not currently have Land Use Planning Zones associated with them.

The generation of Individual Risk Transects from the different methodologies are of interest because they graphically display the falling risk with distance from a pipeline, and so the distances to 10^{-5}, 10^{-6} and 3×10^{-7} can be read directly off the graphs.

The three most relevant assessments are:-

- HSE Gasoline Pipelines Risk Assessment Methodology 1999
- W S Atkins Report 1998 "Assessing risks from Gasoline Pipelines in the UK based on historical experience"
- A D Little 1996 report – published as HSE Contract Research report 206/1999

Main comments on these studies are as follows:-

1 The HSE methodology is based on elements from the two other studies, using failure rates derived from its own failure data banks, pool spreading on impervious clay soils (no soaking into the ground), and using AD Little's concept of 100 metres diameter delayed ignition pools and probability of ignition data.

2 **The HSE assumption that a pinhole leak (10 mm hole) accumulating 458 tonnes of gasoline over a 24 hour period, the pool then igniting and burning in 15 minutes causing a dangerous dose over 120 metres diameter, is extraordinary. Due to the higher frequency of pinhole leaks used in their analysis, ~ 50% of the risk comes from this one unrealistic scenario.**

3 AD Little report shows that for a pinhole leak, the pool diameter on average soil is 19 metres diameter, and for clay soil is 73 metres diameter. WS Atkins point out that in UK, very impermeable clay soils are relatively uncommon. Taking 100 metres is therefore unjustifiably conservative

4 WS Atkins analyse extensive historical data and come to the conclusion that there are no risks above 3×10^{-7} for any size of gasoline pipeline in the UK. One key assumption in their analysis is that there is 10% probability of fatality in the area affected by a pool fire or spray fire. This based on historical data which shows there is a high probability of escape from such incidents.

5 For a 6 inch diameter pipeline, the following distances are obtained:-

	Distance to 10^{-5}	Distance to 10^{-6}	Distance to 3×10^{-7}
HSE Methodology	-	43	54
W S Atkins	-	-	-
A D Little	-	5	36

The AD Little assessment was for “average” soil rather than for clay-type soil.

6 WS Atkins report indicates that AD Little have under-estimated soil permeability by an order of magnitude so gasoline pool sizes are pessimistically large in the ADL assessment.

7 WS Atkins report indicates that AD Little have over-estimated thermal radiation effects by up to 8 times due to simplistic modelling of radiation dose effects. HSE model may be using a similar model to the WS Atkins model rather than ADL model.

8 The 3 analyses have used different failure rate data:-

Per 1000 km.years	Pinhole	Puncture	Rupture	Total
HSE Methodology	0.289	0.171	0.0373	0.4973
W S Atkins	-	-	-	0.66 urban 0.25 rural
A D Little	0.206	0.164	0.051	0.42

HSE methodology is based on 4 holes sizes, but only uses 3 in the example given.

WS Atkins assume same failure rate for all pipeline sizes based on CONCAWE data, but with an extraordinary allocation factor to urban and rural failures (see below).

AD Little uses the same failure rates for urban and rural, all pipeline sizes, based on pipewall thickness only. Failure rates shown are for 5-10 mm wall thickness. ADL assume puncture = 80 mm hole which gives a release rate greater than the pumping rate, so the failure rate for puncture has the same consequence analysis as for rupture (= pipeline diameter).

In other words there are effectively only 2 scenarios, both with similar frequency, these being rupture and pinhole.

9 Population risks are assessed as follows:-

Per 1000 km.years	Population indoors	Population Outdoors
HSE Methodology	Same as outside within piloted ignition range (14.7 kW/m2), protection outside this range	100% fatality in pool area Probit applied for probability of fatality above 500 tdu
W S Atkins	Same as outside	10% fatality in pool fire area or spray fire area – allows for escape and shelter
A D Little	Same as outside	100% fatality in pool area Linear effect to 1% fatality at 10 kW/m2 from edge of pool

10 Conclusion

The WS Atkins report is the most comprehensively researched and argued of the risk assessments. It takes into account 2 major factors based on observation from many hundreds of incidents world-wide:-

(a) the permeability of the soil is a major factor which reduces the potential size of pools of gasoline formed following a leak or rupture. In the case of leaks, major pools are very unlikely (the leak occurs under the surface anyway) so HSE's modelling of risk zones based largely on the delayed ignition leak scenario is seriously flawed.

(b) the timescale and development of major releases involving gasoline pipelines allows sufficient time for people nearby to escape. The smell and evidence of a release is plainly obvious and WS Atkins believe that escape should therefore be factored into the risk assessments.

Combined with the lower risk of release from UK pipelines, the conclusion is that the risk levels from gasoline pipelines are lower than the minimum 3 x 10^{-7} for the Outer Zones, and so gasoline pipelines do not require Land Use Planning zones to be specified for PADHI.

Contrasting Assumptions

	HSE Methodology	**W S Atkins**	**A D Little**
1 Failure rate data -	Conservative compared to UK CONCAWE	Very conservative – also uncertain derivation	Conservative – shows effect of using UK CONCAWE data
2 Scenarios	Immediate and delayed pool fire	Immediate pool fire and spray fire	Immediate and delayed pool fire
3 Source of ignition probability	Immediate ignition – average Delayed ignition – Conservative	Immediate ignition Urban – conservative Rural - average	Immediate ignition – average Delayed ignition average
4 Pool size –	Very conservative –	Average	Conservative –

immediate /soil permeability	impervious clay only	(uses actual sizes)	order of magnitude too low
5 Pool size -delayed	Very conservative – assumes 468 tonnes accumulates from a 10 mm hole	Average	Conservative – takes into account soil permeability
6 Pool fire radiation model	Average – PFIRE 6	Average – PFIRE 6	Conservative – 8 times too high
7 Outdoors vulnerability	Conservative – assumes no escape from pool	Average – allows escape from spreading pool – 10% fatality	Very conservative – no escape from pools
8 Indoors vulnerability	Conservative – Minimal protection from buildings (re BLEVE models)	Average – allows protection to be assumed – 10% fatality	Conservative – no allowance for sheltering inddors

R A McConnell
19 November 2003

1 HSE Gasoline Pipeline, Risk Assessment Methodology, April 1999

HSE developed the computer program PIPERS which is derived from similar modelling for gas pipelines. It evaluates thermal radiation effects from spreading or bunded pool fires. The report contains a partially worked example which is quoted here.

1.1 Safety-related risk scenarios

Immediate ignition – 2.5% of spills ignite immediately. The pool of gasoline spreads until the burning rate of the pool equals the release rate from the pipeline.

Delayed ignition – 2.5% of the remaining 97.5% (= 2.45%) of spills. Delayed ignition cases occur for all release rates is assumed to be in a bunded diameter pool of 100 metres.

Therefore 95.05% of spills are assumed not to ignite.

1.2 Failure type and frequency data

Failure rates can be used from 3 sources – fracture mechanics predictive models, calculations from simple models based on historical data, and user input.
Example quoted is for a 6” diameter pipeline in an urban environment with the following failure rates:-

Rupture	0.0373 per 1000 km-years
Large hole	0.171 per 1000 km-years
Medium hole	ignored
Small hole (pinhole)	0.289 per 1000 km-years

1.3 Consequence type and dimensions, consequence zones

The analysis considers pool fires only. Two types of pools are considered:-

(1) those which ignite immediately and grow until the burning rate of the gasoline = release rate from the pipeline. Actual dimensions are not given in their report, but are likely to be similar to those given in the WS Atkins report. 100% fatalities are assumed in the pool fire.

(2) delayed ignition pools are assumed to grow until they are 100 metres in diameter (this includes “pinholes” which take 24 hours to grow to this size (!).

As stated in Appendix B of the HSE report:-
“The bund diameter is set to 100 metres for all hole sizes. This might seem a little large for a pinhole; it is however, quite reasonable. PIPERS models the fire over a 15 minute period. A 10 mm hole delivers petrol to the pool at 5.3 kg/sec. Thus in 24 hours (86400 seconds) a total of 457.92 tonnes will be delivered to the pool if the pool is not ignited. If it is then burnt in the 15 minute period, this is a burning rate of 509 kg/sec which is similar to the burning rate of a 100 metres diameter pool”. This is an extraordinary assumption.

Dimensions (as given in WS Atkins report) are as follows:-

Pipeline diameter	Hole size	Release rate Kg/sec	Pool diameter (metres) Immediate ignition	Delayed
16” (406 mm)	Rupture	205	62.7	100
12.75” (324 mm)	Rupture	164	55.8	100
8 5/8” (219 mm)	Rupture	100	43.6	100
6 5/8” (168 mm)	Rupture	30	23.9	100
All	10 mm leak	5.3	10	100

1.4 Pool fire radiation

Pool fire is based on PFIRE6 model for flame radiation from W S Atkins. Consequence analysis is complicated by considering upwind, downwind and sidewind effects from the pool fires, although effects are small compared to pool fire diameters. 4 wind weather conditions can be considered although 2 are used in the example (D5 and F2). Dangerous dose effects are calculated to 1000 tdu from the pool fires. Sheltering indoors is effective except where thermal radiation exceeds piloted ignition flux of 14.7 kW/m2. At levels above this occupants are assumed to vacate the building and receive the outdoors radiation dose.

For the 6" pipeline case (and F2 wind weather), distance from the centre of the pool fire to the 1000 tdu effect level for each case is as follows:-

Rupture pool fire radiation, immediate ignition, to 1000 tdu = 36.4 metres
Large hole pool fire radiation, immediate ignition, to 1000 tdu = 33.2 metres
Pinhole pool fire radiation, immediate ignition, to 1000 tdu = 5.5 metres
Rupture pool fire radiation, delayed ignition bunded, to 1000 tdu = 59.7 metres
Large hole pool fire radiation, delayed ignition bunded, to 1000 tdu = 59.7 metres
Pinhole pool fire radiation, delayed ignition bunded, to 1000 tdu = 59.7 metres

These thermal radiation levels may be more realistic than those calculated by AD Little (full discussion of this below).
Taking the 6" diameter pipeline pool fires:-

Pipeline diameter	HSE Pool radius	HSE Distance to 1000 tdu	AD Little – pool radius	AD Little – distance to 1% fatality = 10 kW/m2
6" immediate ignition	12 metres	33-36 metres	13 metres	40 metres
6" delayed ignition	50 metres	59.7 metres	50 metres	126 metres

However WS Atkins report that the AD Little method may be over-estimating some radiation levels by up to a factor of 8.

1.5 Population impact

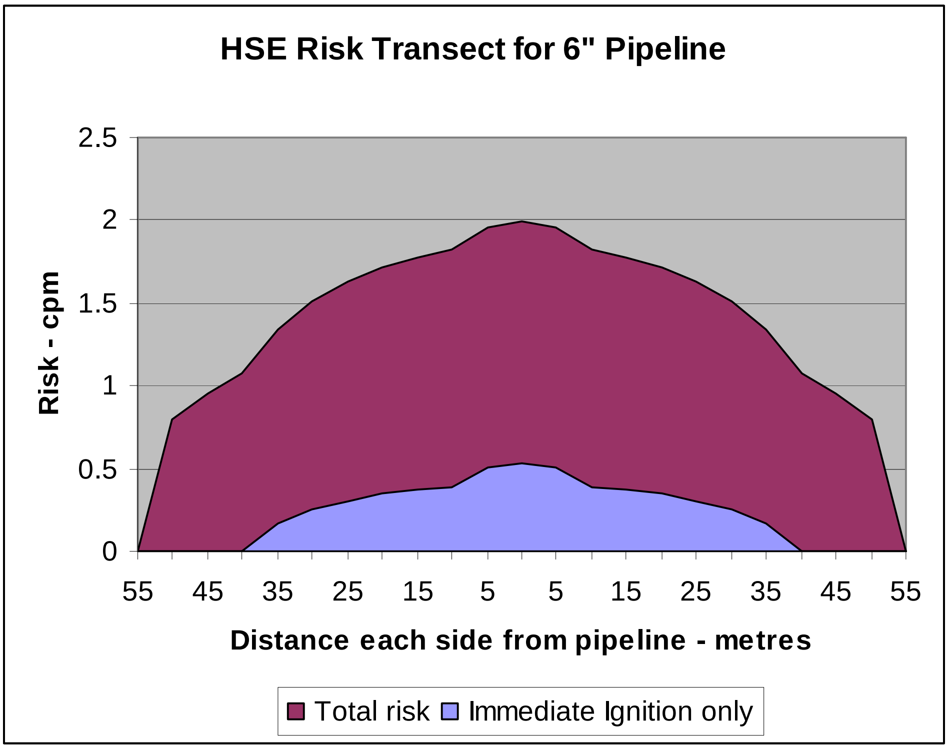
The approach in HSE's PIPERS is based on similar modelling produced for gas pipelines, including sheltering in buildings and escape from thermal radiation. However these effects are shown to be of minimal impact on the calculations – the consequence analysis and population impact is dominated by the assumption that there are 100% fatalities within the pool fire radius both indoors and outdoors, and that fatality levels outside the pool fire are similar for outdoor and indoor population due to the escape fatality assumption from buildings exposed to >14.5 kW/m2.

1.6 Analysis results

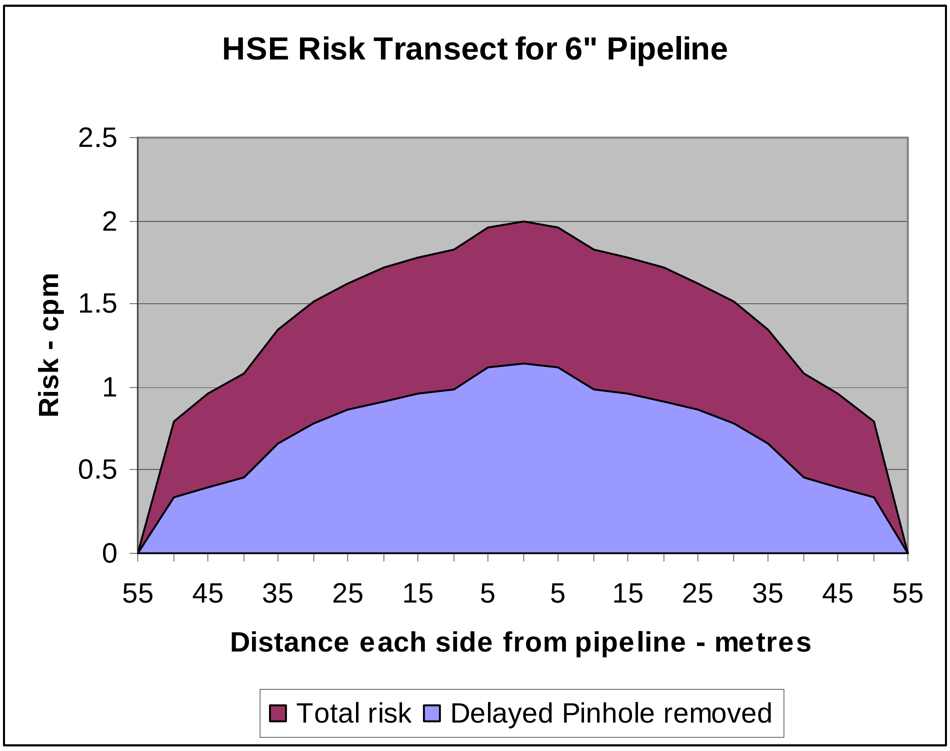
Results below show the risk transects based on the HSE methodology. Estimates of D% weather conditions have been made because these have not been given in the HSE report. From these transects it is apparent that:-

(a) "Pinholes" (i.e. 10 mm holes) causing a delayed pool fire have by far the greatest effect on risk because they have the highest frequency, and are assumed to form a 100 metres diameter pool.

(b) Delayed ignition cases dominate the risk yet no escape probabilities are included in the analysis



This transect shows the total risks calculated for a 6” pipeline based on the data given in the HSE report. The effect of removing the delayed ignition cases is shown by the lower curve, and demonstrates that the risks reduce to very low levels if these cases are removed.



Note risks are shown a cpm = chances per million per year.
1 cpm = 10^{-6} per year. There the two levels of interest are 1 cpm and 0.3 cpm.

2 W S Atkins "Assessing the Risk from Gasoline Pipelines in the UK based on a review of historical experience", July 1998

This was an external research report commissioned by the HSE to ascertain the degree of risk posed by gasoline pipelines in the UK. The maximum calculated levels of individual risk of fatality to a typical residential population close to a gasoline pipeline were 1.4 x 10^{-7} /year in urban areas and 3.2 x 10^{-8}/year in rural areas on the pipeline centre (both well below the Land Use Planning outer zone level of 3 x 10^{-7}).

2.1 Safety-related risk scenarios

Extensive event trees for urban and rural areas were produced, derived from an analysis of international incidents.

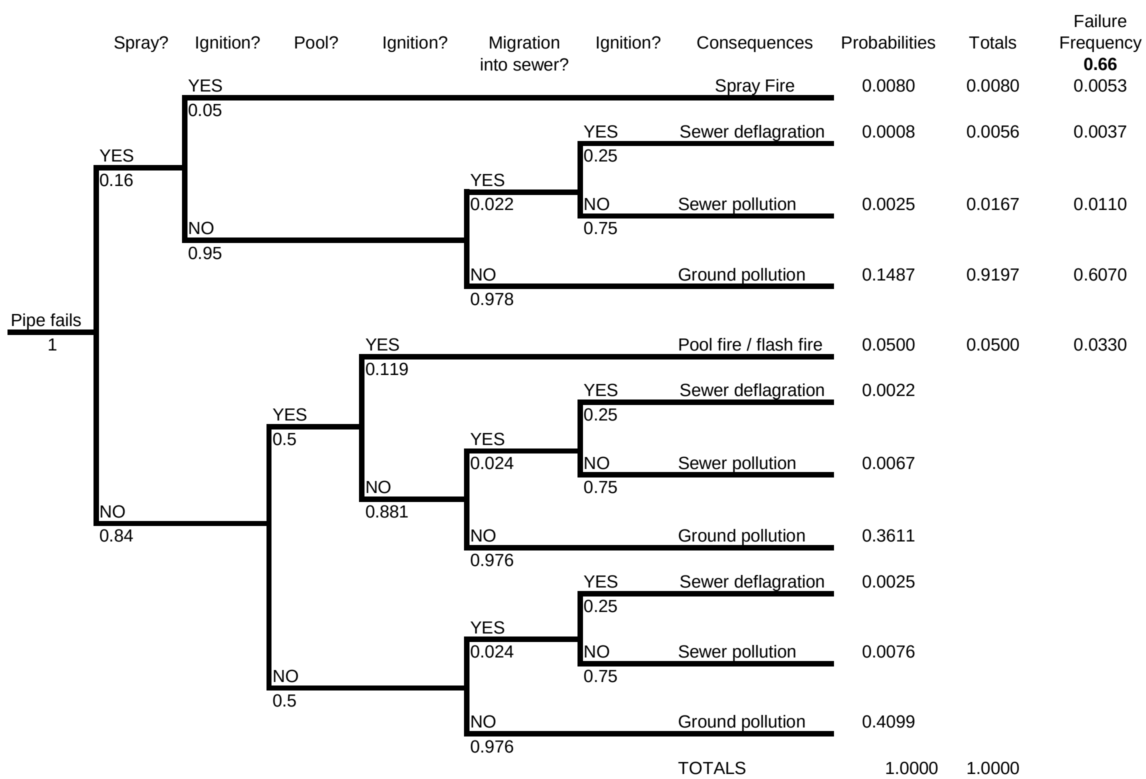
Only two of the scenarios were subsequently evaluated in detail as having direct safety-related risks, these being ignited spray fires, and pool fires. Delayed ignition in sewers in urban areas were not evaluated as safety risks, nor were delayed ignition in watercourses in rural areas. (these risks are relatively small anyway).

Immediate ignition – 16% of total releases were found (from historical data) to be sprays of which 5% ignited giving an overall probability of 0.8%.

Pool formation - 42% of total releases were found to form pools of which 11.9% ignited giving an overall probability of 5%.

Delayed ignition – is not evaluated as having a safety-related risk in the Event Trees, although deflagration in sewers is recognised as a risk:-

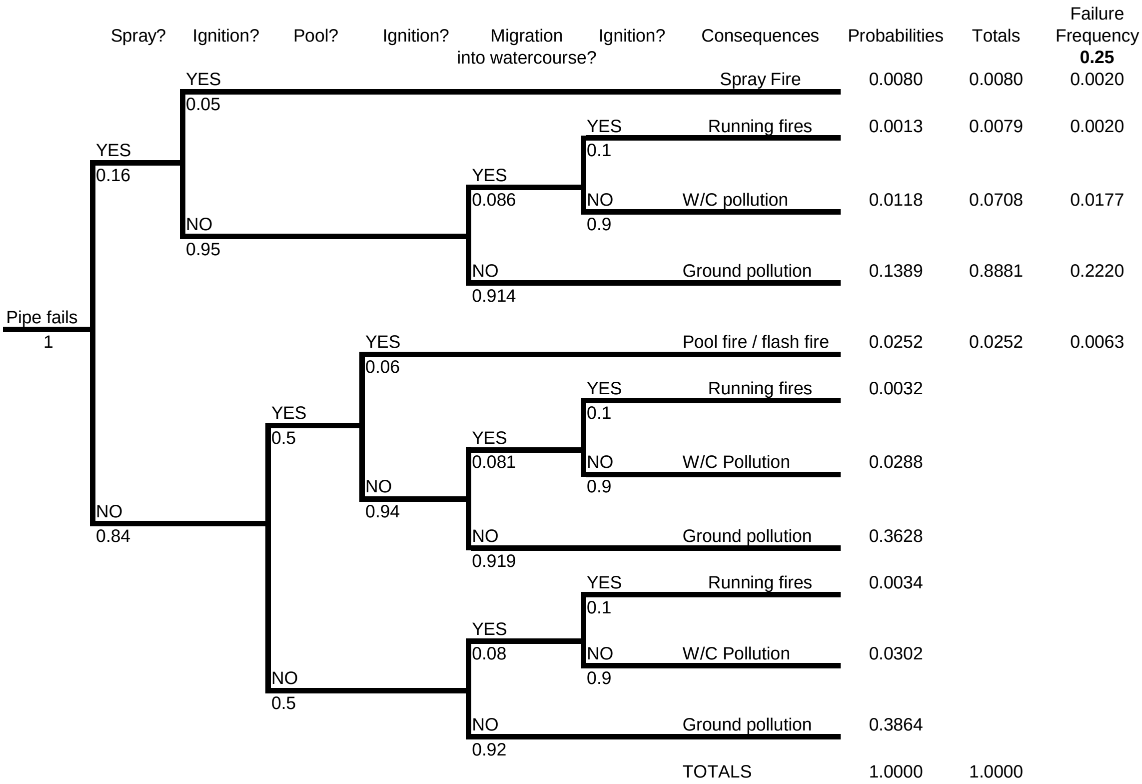
W S Atkins Event Tree for releases in Urban Areas



Therefore 93.64% of spills are assumed not to ignite.

The Event Tree for Rural releases is as follows:-

W S Atkins Event Tree for releases in Rural Areas



In this case Watercourse pollution (W/C pollution) is higher than the equivalent sewer pollution in urban cases, and the probability of no ignition is higher at 95.89%.

2.2 Failure type and frequency data

Failure rate data is taken from CONCAWE 1971-1996. Failure rate of 0.29 per 1000 km-years is re-assigned on the following basis:-

86% of CONCAWE incidents can be assigned as Rural, Commercial, Industrial or Residential. Re-assigning these proportions to make 100% gives the following:-

Proportion of incidents occurring in Rural areas = 77%
Proportion of incidents occurring in Residential, Industrial or Commercial = 23%

In the UK land use areas for Rural is 90%, and for the rest is 10%.

Therefore 23% of the incidents occur in 10% of the land area in UK,
so the failure rate for Urban Areas = (23/10) x 0.29 = 0.66 per 1000 km-years

For Rural, 77% of the incidents occur in 90% of the land area in UK,
so the failure rate for Rural areas = (77/90) x 0.29 = 0.25 per 1000 km-years

These are the failure rates used in the Event Trees to derived the risk contours. The basis for this analysis is not clear and is somewhat questionable.

2.3 Source of ignition data

An extensive listing of incidents is contained in the report from which the following analysis is derived (Table 3.15):-

Fuel	No of Incidents	No of fires	Probability of Ignition
USA DOT Data			
Gasoline	284	10	3.5%
Jet Fuel	35	2	5.7%
Kerosene	9	0	0
All	328	12	3.7%
CONCAWE Data			
All	101	3	3.0%

Of the 3 CONCAWE incidents reported, 2 occurred in rural areas (2.5%) and 1 in urban areas (4.3%). In their Event Trees, WSA derive 2.5% for pool fire ignition in rural areas and 5% in urban areas.

2.4 Areas Affected by Releases and Pool Formation

Unlike other assessments. WSA do not analyse failures by hole size. Their analysis takes into account release rates and duration of release by examining CONCAWE data, of which about 50% had a figure recorded for land pollution. The data used for assessing the risk transects for gasoline pipelines is taken from an analysis of this data and given Table 3.19:-

Radius of Release - metres	Percentage of releases
Less than 5	35%
5 – 10	14%
10 – 20	21.5%
20 – 30	17.5%
30 – 50	4%
more than 50	8%

“Incidents giving a radius of more than 50 metres are mainly releases onto watercourses and on river banks etc. and are therefore not particularly relevant to a consideration of spread on ground. Table 3.19 amplifies the point that the vast majority of releases result in only a small ground spread”

2.5 Release Rates and Spreading Pools

Although not used in the analysis of Risk Transects, WSA give an interesting insight into release rates and spreading pools, during which the 100 metre diameter delayed ignition pool re-appears from the ADL 1996 study:- (Table 5.3)

Pipeline diameter	Hole size	Release rate Kg/sec	Pool diameter (metres) Immediate ignition	Delayed
16” (406 mm)	Rupture	205	62.7	100
12.75” (324 mm)	Rupture	164	55.8	100
8 5/8” (219 mm)	Rupture	100	43.6	100
6 5/8” (168 mm)	Rupture	30	23.9	100
All	10 mm leak	5.3	10	100

These pools do not take into account soil permeability, and assume no soaking into the soil. “Previous studies [i.e. ADL] have used absolute permeabilities of 10^{-12} m^2 and 10^{-16} m^2 to characterise average and clay soils respectively.

It should be noted that the dynamic viscosity of gasoline is 4 times less than water, so the coefficient of permeability of gasoline will be about 4 times greater.”

As a result, for average soil conditions, pool diameters change as follows:-

Pipeline diameter	Hole size	Release rate Kg/sec	Pool diameter (metres) Immediate ignition Impervious	Average	Delayed Imp	Average
16” (406 mm)	Rupture	205	62.7	43	100	59.4
12.75” (324 mm)	Rupture	164	55.8	38.5	100	53.1
8 5/8” (219 mm)	Rupture	100	43.6	30.1	100	41.5
6 5/8” (168 mm)	Rupture	30	23.9	16.5	100	22.7
All	10 mm leak	5.3	10	6.9	100	9.5

Permeabilities derived and used are an order of magnitude higher (i.e. more absorbent) than used by AD Little in their assessment of “average” and clay soils.

“It should be emphasised that the pool diameter on permeable soils is very sensitive to the precise value of the coefficient of permeability – on a very permeable soil the maximum pool diameter for delayed ignition of the 205 kg/sec release is only 5.9 metres.
It should also be noted that very impermeable clay soils are relatively uncommon in the UK.”

2.6 Fatalities in Pool Fires

Pool spreading is relatively slow – less than 1 metre/second in diameter, which should allow easy escape by walking away from a spreading pool at 2.5 m/sec. In simple models (ADL) the time dependent growth of the pool is not considered. There may be sufficient time for people very close to the release to escape by simply walking away.

“**On flat ground the rate of spreading is so low that it should pose very little risk to anybody outdoors unless they are right on top of the leak site (i.e. people able to detect from even a short distance away that the release has occurred, would generally be able to walk away). This implies that the standard pool fire models which assume the instantaneous formation of a large fixed diameter pool, have little relevance in terms of calculating a risk of fatality**.”

“For the purposes of this study, the area that may be affected by a pool fire is based on the distribution of spillage radii given in Table 3.19. However it should be noted that these are based on measurement of contaminated ground, often involving small pools of gasoline or drenched top soil. Therefore this is a conservative assumption. It is also assumed that the area affected is circular. It is assumed that the fraction of people who suffer fatality within the affected area is about 10%.”

2.7 Thermal Radiation Model

WSA have developed POOLFIRE6 model for HSE. It models the steady-state pool fire, not the growing pool fire as the pool grows.

It allows for wind speed causing flame drag and tilt in the downwind direction. It uses an obscuration factor of 0.02 for all gasoline pool fires – this represents a smoky flame with relatively small amount of the heat being radiated from the flame surface.

“It is interesting to note that for the zero wind speed case, POOLFIRE6 tends to predict significantly lower radiation intensities than those calculated by ADL.”

WSA also refer to the ADL approach of calculation the distance to the 10 kW/m2 thermal radiation level using 1% risk of fatality at this level:-

“All the risks quoted beyond the pool fire are not based on radiation intensity or thermal load as is standard practice, but rather on an arbitrary interpolation down to 1% risk of fatality at 10 kW/m2. By using linear interpolation the risks at some distances may be overestimated by a factor of 8”.

However, WS Atkins appear to use the pool diameters as defined in Table 3.19, as the consequence distances for producing the risk transects. Distances to specific thermal radiation effects do not appear to be calculated.

2.8 Spray Fires

Analysis of USA DOT reports indicates that 16% of incidents have involved spray releases for some period, although only 3.5% of the reports included a definite reference to sprays. Of the 101 CONCAWE reports only 1 spray incident is confirmed. From the WSA Event Trees, the probability of an ignited spray fire is 0.008.

WSA propose the following empirical formula for spray range:-

Range of spray (metres) = 2 x pressure (bar)

So for an 80 bar gasoline pipeline, the spray range is 160 metres. To model the spray effects, WSA use 4 elliptical spray models, each with a probability of 0.25:-

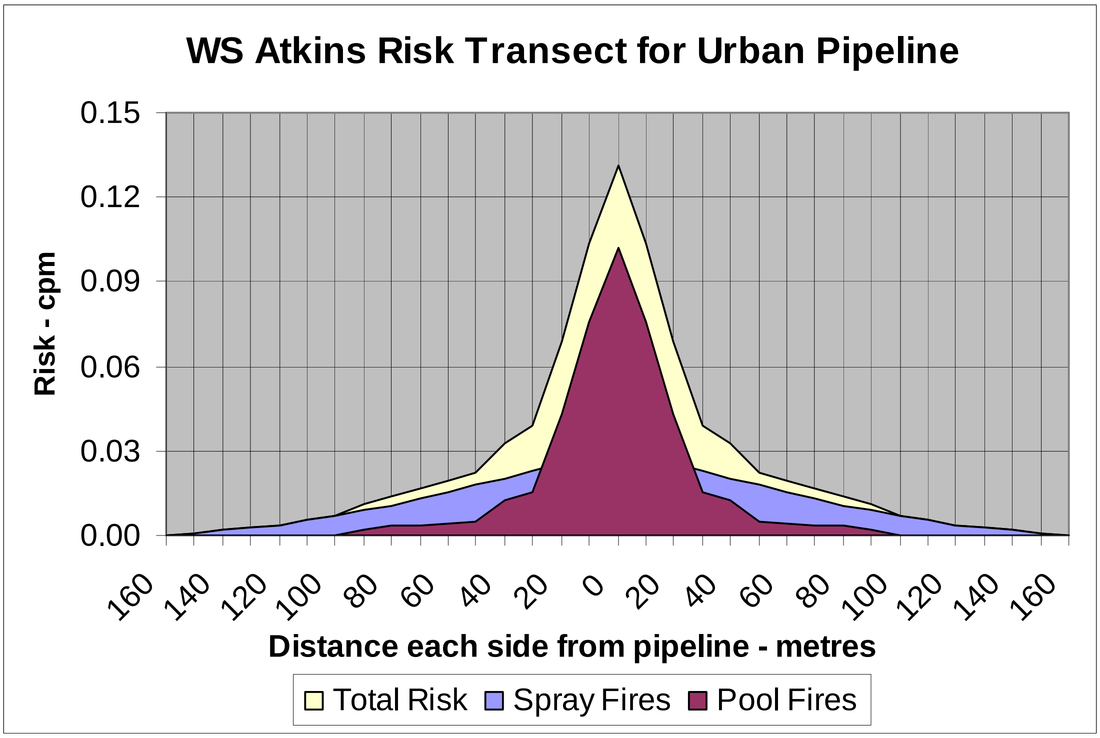
(1) Major axis = 160 metres, minor axis 80% of 160 metres = 128 metres
(2) 120 metres and 96 metres
(3) 80 metres and 64 metres
(4) 40 metres and 32 metres

The probability of being affected by a spray release can therefore be calculated in a similar way to a gas cloud release from a pipeline.

For ignited sprays, it is assumed that for a typical residential population, 10% of those in the elliptical footprint would suffer fatality.

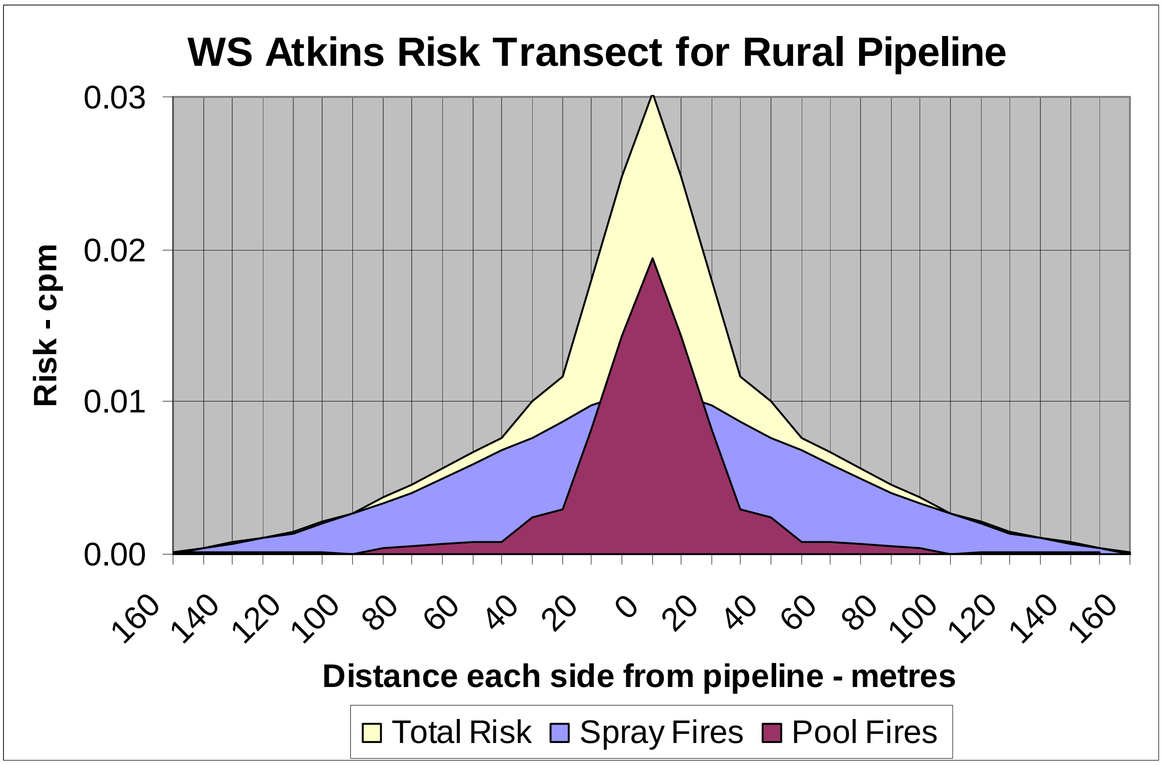
2.9 Risk Transects

The following risk transects have been derived using WSA's method for calculating the risks:-



[Note these appear differently in WSA report which plots risk as log scale]

This shows the peak risk of 1.4 x 10^{-7} per year on the pipeline, with the risk reducing to below 3 x 10^{-8} per year at a distance of 35 metres from the pipeline.
For Rural pipelines, the risk transect is:



3 Arthur D Little Ltd "Risks from Gasoline Pipelines in the United Kingdom" Contract research report 206/1999

The risks from gasoline pipelines in the UK have been calculated and found to be generally low, with distances to 10^{-6} per year being limited in extent in many cases, or non-existent, and centre-line risks never above 10^{-5} per year.

3.1 Safety-related risk scenarios

Release scenarios are based on conventional 3 scenario release cases:-

Pipeline rupture = diameter of pipeline

Puncture = 80 mm hole

Leak = 10 mm hole

Safety-related scenarios considered are pool fires only.

Ignition probabilities are derived from historical data for immediate and delayed ignition scenarios. Pools are derived for immediate and delayed ignition based on "average" and clay soil conditions.

3.2 Failure Rate Data

An analysis of EGIG and CONCAWE data leads to the conclusion that pipewall thickness is the defining parameter for failure rates. All pipelines in the study have wall thicknesses between 5 and 10 mm so the failure rates used are as follows:-

Leak	Hole	Rupture	Total
Per 1000 km-years			
0.206	0.164	0.051	0.42
49%	39%	12%	

No distinction is made for failure rates in urban and rural areas.

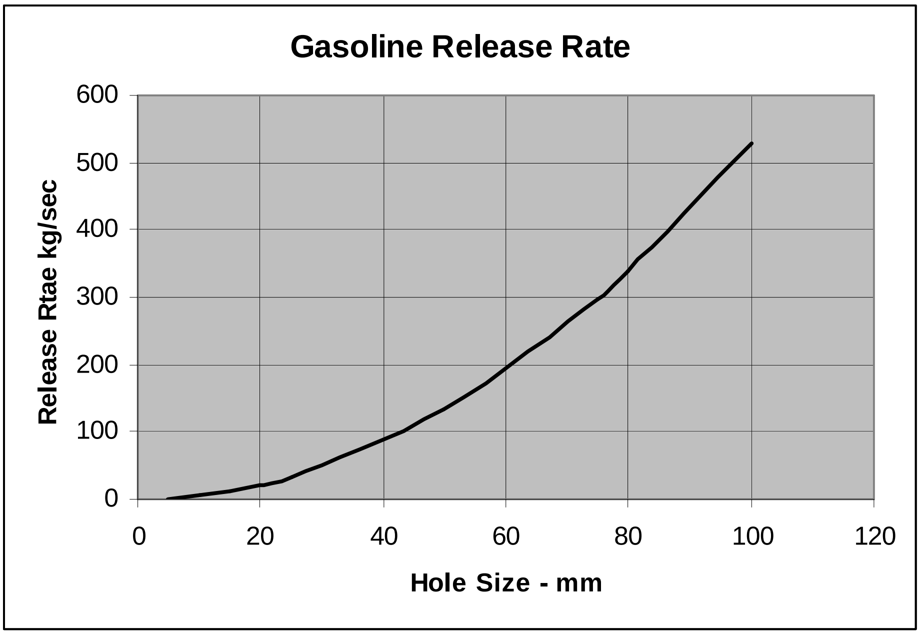
3.3 Hole sizes and release rates

Three hole sizes are defined, 10 mm pinhole, 80 mm puncture, and line diameter rupture.

Release rates are defined either by pumping rate, or by leak rate calculations for hole sizes.

Pipeline diameter	Hole size	Release rate Kg/sec
16" (406 mm)	Rupture	205
12.75" (324 mm)	Rupture	164
8 5/8" (219 mm)	Rupture	100
6 5/8" (168 mm)	Rupture	30
All	10 mm leak	5.3

The graph below shows the release rate plotted against hole size for 80 bar gasoline.
80 mm hole has a release rate of 340 kg/sec, therefore the 80 mm hole is treated as if it was a pipe rupture release.



Therefore only 2 scenarios are considered:-

Leak	Hole and Rupture	Total
0.206	0.215	0.42
49%	51%	

3.4 Pool Formation and Spreading

Two cases are considered, "average " soil with permeability 10^{-12} m^2 and clay soils 10^{-16} m^2.

"Spillages onto clay soils are not readily absorbed into the ground and may theroretically continue to spread for many hours. Clearly the shutoff times would be important in predicting maximum pool size. However the formation of such large pools would require a very extensive area of either totally flat or basin-shaped terrain, with no cracks, fissures or drainage or containment in any catering produced as a result of the failure. The formation of such large pools is therefore extremely unlikely and pool sizes have been limited to 100 metres diameter throughout the study to account for these features in a generic way."

Pool sizes are calculated for spreading pools for immediate ignition cases and for bunded pools for delayed ignition cases:-

Pipeline diameter	Hole size	Release rate Kg/sec	Pool diameter (metres) Immediate Ignition
16" (406 mm)	Rupture	205	68.9
12.75" (324 mm)	Rupture	164	62
8 5/8" (219 mm)	Rupture	100	48
6 5/8" (168 mm)	Rupture	30	26
All	10 mm leak	5.3	11

For delayed ignition cases, the pool sizes are effectively limited by the assumed shutoff times which ADL have used, as follows:-

Pipeline diameter	Release rate Kg/sec	Soil type	Pool diameter (metres) Immediate Ignition
16" (406 mm)	205	Average Clay	100 100
12.75" (324 mm)	164	Average	100
8 5/8" (219 mm)	100	Average Clay	85 100
6 5/8" (168 mm)	30	Average	46
All – 10 mm leak	5.3	Average Clay	19 73

Shut off times assumed are 6 to 25 minutes for large releases and 35 minutes to 3 hours 20 minutes for 10 mm holes.

3.5 Pool Fire Radiation Effects

ADL use a 3 –part flame model with different surface emissive powers to calculate the thermal radiation from pool fires. They then calculate the distance to 10 kW/m^2 as the 1% fatality level. This results in very large hazard ranges (see discussion in WSA section above):-

Pipeline diameter	Hole size	Release rate kg/sec	Pool diameter (metres)	10 kW/m2 effect diameter - m
16" (406 mm)	Rupture	205	68.9	182.4
12.75" (324 mm)	Rupture	164	62	166
8 5/8" (219 mm)	Rupture	100	48	134
6 5/8" (168 mm)	Rupture	30	26	80
All 10 mm leak	10 mm leak	5.3	11	38
Delayed ignition			100	252

As stated in WSA report:-

"All the risks quoted beyond the pool fire are not based on radiation intensity or thermal load as is standard practice, but rather on an arbitrary interpolation down to 1% risk of fatality at 10 kW/m^2. By using linear interpolation the risks at some distances may be overestimated by a factor of 8".

3.6 Source of Ignition Probability

ADL examine USA DOT data to obtain ignition probabilities as follows:-

Scenario	Immediate Ignition	Delayed Ignition	No Ignition
Urban Area - Ruptures and Holes	0.031	0.031	0.939
Urban Area – Leaks	0.006	0.006	0.988
Rural Area – Ruptures and holes	0.016	0.016	0.968
Rural Area – Leaks	0.003	0.003	0.984

3.7 Summary of Individual Risk Results

ADL have analysed several sets of data and applied sensitivity analysis as shown. In addition they have applied sensitivity analysis to the failure rates used, using

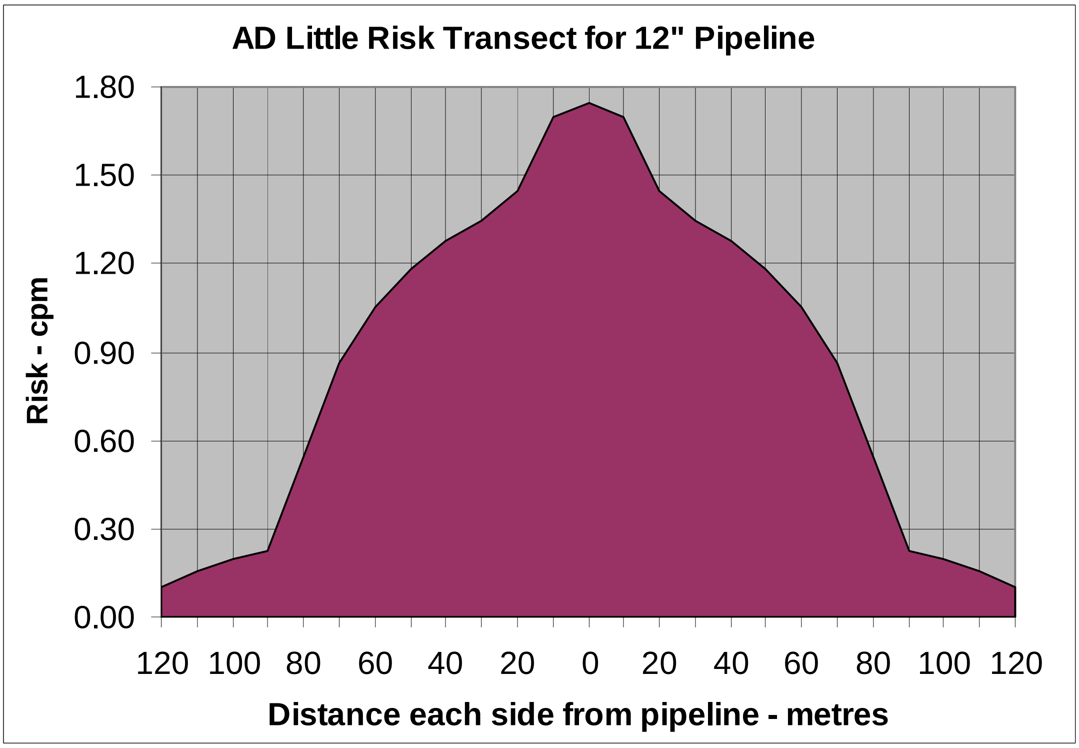
High	-	EGIG	-	0.57 per 1000 km.years
Medium	-	CONCAWE Europe	-	0.42 per 1000 km years
Low	-	CONCAWE UK	-	0.3 per 1000 km years

ADL present the following results:-

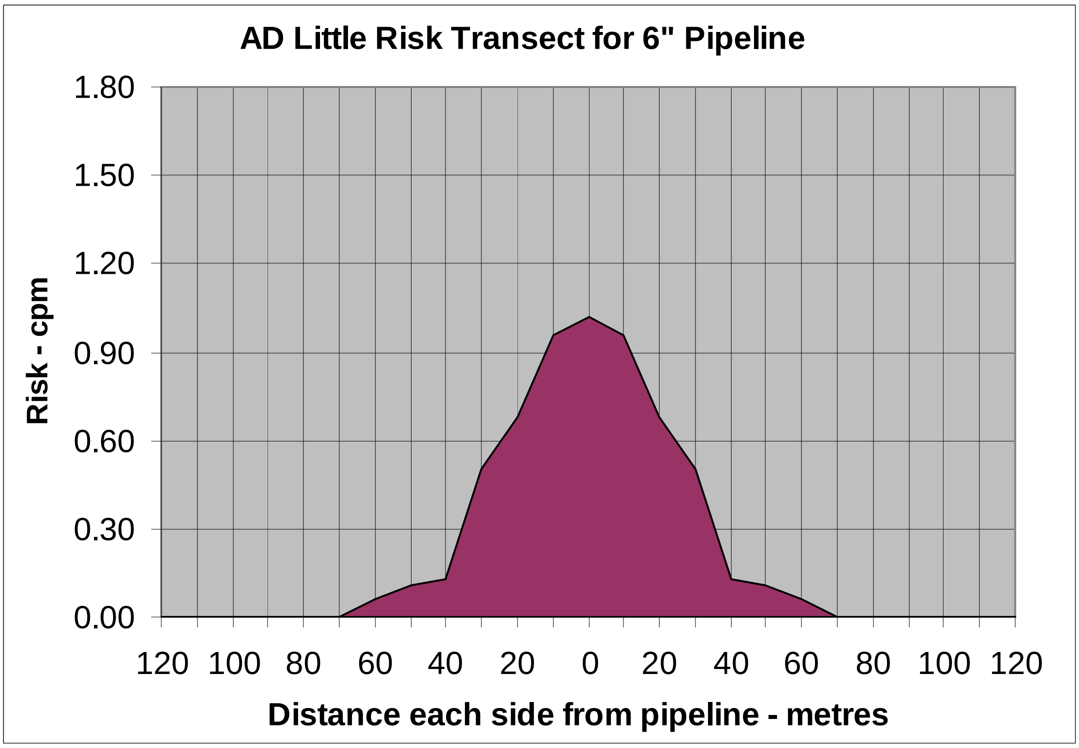
Pipeline diameter	Location	Sensitivity bound – failure rate	Soil Type	Shut off time if clay soil	Burial Depth Metres	Distance To 10^{-6} / yr	Distance to 3 x 10^{-7} / yr
16” (406 mm)	Urban Urban Urban Rural	High High Medium Medium	Clay Average Average Average	Good/poor	0.9 0.9 0.9 0.9	78 74 65 -	104 100 95 80
12.75” (324 mm)	Urban Rural	Medium Medium	Average Average		0.9 0.9	61 -	95 77
8 5/8” (219 mm)	Urban Urban Urban Urban Urban Urban Urban Rural Rural Rural	Medium Medium Medium Medium Medium High Low High Medium Low	Clay Clay Average Average Average Average Average Average Average Average	Poor Good	0.9 0.9 0.9 2 3 0.9 0.9 0.9 0.9 0.9	61 51 45 30 24 54 27 23 - -	92 86 78 74 69 85 71 69 61 50
6 5/8” (168 mm)	Urban Rural	Medium Medium	Average Average		0.9 0.9	5	36 26

3.8 Individual Risk Transects

12" gasoline pipeline, average soil, urban - 10^{-6} (1 cpm) at 61 metres, 0.3 cpm at 95 metres



6" gasoline pipeline, average soil, urban - 1 cpm at 5 metres, 0.3 cpm at 36 metres



4 A D Little, 1994 report - HSE Contract Research Report 82/1994

This was the initial ADL study which examined several substances conveyed by cross-county pipeline to:-

- Demonstrate a methodology for individual and societal risks for onshore pipelines
- Apply the methodology to a representative sample of hazardous materials
- Examine the individual and societal risks
- Draw broad conclusions

The sample gasoline line considered was 8 5/8 “ diameter operating at 80 bar, wall thickness 0.203 inches and design factor 0.54.

The failure derived for the gasoline pipeline was 0.42 per 1000 km.years (same as the later 1999 study).

A typical hazard range of 107 metres was derived for the thermal radiation from a pool fire after delayed ignition following a full bore rupture. No other details are given so it is not possible to replicate the resulting risk transect.

The risk transect shows:-
Peak risk on pipeline = 1.8×10^{-6}
Distance to 10-6 = ~ 25 metres
Distance to 3 x 10-7 = ~ 60 metres

5 TNO report for DG XI to review major hazard pipelines, 1997

This report was produced in 1997 on instruction from the European Commission DG-X1 to be used in the Workshop on Major Pipeline Hazards in October 1997 in Berlin.

The assessment was for consequence analysis only – failure frequencies and risks were not assessed.

Gasoline was included as typical of a highly flammable liquid.

Three pipeline diameters were considered: 6”, 12” and 24”, 3 levels of pressure, 10 bar, 25 bar and 75 bar, full bore rupture occurs, which is detected and corrected in 300 seconds (5 minutes). Release rate is 1.5 times pumping rate. Remaining material in the 10 kilometre length between sectioning valves is assumed to leak out.

1% lethality is assumed to occur for heat radiation levels 12.7 kW/m2 and 20 seconds. Environmental as well as safety aspects were considered.

Consequences of releases are shown in Table A6 for gasoline, pool fire effects were as follows:-

Diameter inches	**Pressure bar**	**Release rate Kg/sec**	**Pool radius metres**	**Pool fire 1% fatality**
6	10	11.5	21	66
	25	19.5	23	72
	75	20.1	23	73
12	10	78.8	47	128
	25	80.5	47	128
	75	80.5	47	128

Diameter inches	Pressure bar	Release rate Kg/sec	Pool radius metres	Pool fire 1% fatality
24	10	321.9	94	204
	25	321.9	94	204
	75	321.9	94	204

:-

In addition, assessments are made of flash fires and explosions assuming evaporation from the pool followed by delayed ignition. Access to the full set of assumptions is not available, although there has been no historical evidence that gasoline pipeline releases result in flash fires with extended ranges (up to 624 metres in the TNO assessment) , or of damaging explosions (up to 1177 metres). TNO use the Multi-Energy method for assessing the explosion overpressures assuming:-

(a) all the gasoline vapour is enclosed in the semi-confined area

(b) highest Blast Strength (6-10) is applied.

Both of these are extreme worst-cases.

Appendix -Proposal for a Review

Objectives

- To carry out an independent review of QRAs carried out for gasoline in the UK including international experience of incidents

- To assess the sensitivities of the QRAs to key assumptions, and therefore whether using a simple flat-earth model is a grossly pessimistic approach for setting Land Use Planning zones in the UK

- To provide a logical series of arguments leading to a clear conclusion

5 risk assessments under review:-

1 A D Little, 1994 report - HSE Contract Research Report 82/1994

2 TNO report for DG XI to review major hazard pipelines, 1997

3 W S Atkins Report 1998 "Assessing risks from Gasoline Pipelines in the UK based on historical experience"

4 A D Little 1999 report – HSE Contract Research report 206/1999

5 HSE Gasoline Pipelines Risk Assessment Methodology 1999

Proposed approach

1 Read and review each report, identify main assumptions and methodology – produce a brief description of each assessment and its limitations.

2 Compare key parameters which lead to the conclusions in each report, compare and contrast these parameters, assess the sensitivity and dependence of each.

These include
1 failure rate data, rupture, holes, pinholes etc.
2 safety-related risk scenarios
3 consequence types and dimensions, pool fires, sprays etc
4 consequence zones
5 population risks, inside and outside
6 societal risks

Produce tables of parameters, comparing and contrasting data used in each study.

4 Compare and contrast results from the studies, primarily Individual Risk Transects, also consequences and Societal risks. Check calculation assumptions and methods using spreadsheets to replicate methodologies and results

5 List and contrast assumptions made in each report – list them into categories of Uncertainties, Conservatisms, Optimistic, and Pessimistic assumptions

6 Produce report and presentation summarising findings and conclusions