Appendix C

ATKINS

Bethnal Green Gas Holder:

Quantified Risk Assessment for Land Use Planning

Tower Hamlets

Report No: 5054615/R1/Final

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Quantified Risk Assessment for Land Use Planning

A Report Prepared by
Atkins Oil & Gas

On Behalf of
Tower Hamlets

COMMERCIAL IN CONFIDENCE

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Bethnal Green Gas Holder: Quantitative Risk Assessment for Land Use Planning

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SUMMARY

The proposed development at 33-37 The Oval is located within the Inner Planning Zone of the adjacent Bethnal Green gas holder site. The basis of the HSE 'Advise Against' decision has therefore been addressed in relation to the actual risks at the development site.

Detailed information concerning the site and its operation has been used, together with the appropriate publications from HSE, to provide a list of credible potential major hazard accident scenarios from the site. The consequences of the scenarios have been calculated using standard methodologies, and the results matched, where possible, with information supplied from the National Grid COMAH report. Event frequencies have been estimated based both on recommendations of HSE, and also on interpretation of available accident statistics. The combination of consequences and frequencies has enabled the risks to be calculated, and the predictions match closely to the expectations based upon HSE's Planning Zones.

The results show that the individual risk is above the 'broadly acceptable' level, but is not 'intolerable'. They have also shown that the societal risk associated with the population around the gas holder site lies within a similar band, but would be increased by around 32% by the addition of this extra population (of order 60 people) within around 40m of the nearest gas holders. It is therefore concluded that:

1.) The individual risk, at around 12cpm, is not intolerable, but is above the level at which HSE would 'advise against' for this type of development.

2.) The current societal risk associated with the gas holder site is not particularly high for a Top Tier COMAH site.

3.) The addition of the extra population will increase societal risk by around 32%, but it will still remain well within HSE guidelines.

4.) Whilst it is possible that a case could be made for accepting this additional risk, HSE is likely to be concerned at the potential for cumulative societal risk effects if adjacent properties were to be developed in a similar way.

1. INTRODUCTION

1.1 Background

Planning Permission has been granted by Tower Hamlets Council for a development of 14 residential units and 3 small business units at 33 - 37 The Oval, Bethnal Green, London E2. This is a relatively small 5 storey development close to the Bethnal Green gas holder station, which is operated by National Grid.

Since this development falls inside the Inner Planning Zone of the gas holder station, within which HSE would advise against the granting of Planning Permission, Tower Hamlets is seeking an understanding of the actual risks to which users of the development would be exposed. This will provide the Planning Authority with assurance that whatever ultimate planning decision is taken will be based on a full understanding of the risks. This study has therefore been undertaken in response to a request made at a meeting at Tower Hamlets' offices on 27th March 2007.

1.2 Objectives and Scope of Work

The primary objective of this study is to provide realistic estimates of the risks associated with the presence of the Bethnal Green gas holder station which is in close proximity to the proposed development. In order to achieve this, Atkins has followed the scope as agreed with Tower Hamlets, and as set out below:

1) Meet with Tower Hamlets to clarify scope/ requirements.
2) Obtain and assess information regarding gas holder operations from National Grid.
3) Review HSE information regarding recent changes to Planning Zone methodology for gas holders to assess uncertainties and conservatisms, and to determine representative events for consideration in the Quantified Risk Assessment (QRA).
4) Obtain detailed population information (i.e. numbers and types) for areas covered by Planning Zones.
5) Produce QRA of risks from gas holder site, using best estimate methodologies as determined from Task 3, and ensuring that all the event types identified in HSE's Methane gas holders Safety Report Assessment Guide are considered. This will provide estimates of the Individual Risk to the following population types at the development:
    a) Indoor residential population in nearest (top floor) flat.
    b) Indoor office worker in nearest ground floor office.
    c) Outdoor user of communal terrace area at top floor roof level.

   It will also provide estimates of the Societal Risk (risk of large numbers of fatalities arising as a result of a particular incident) associated with the presence of the existing population in the vicinity of the gas holders, together with an estimate of the change to the Societal Risk when the new development is completed and occupied.
6) Assess significance of individual risks at the new development in relation to other everyday risks, and to criteria set by HSE.

The following information was requested to be supplied by Tower Hamlets Council, in order to complete the above scope of work;

1) Details of amounts stated (for each individual gas holder) in the Hazardous Substances Consent.
2) Typical annual operational profile of the gas holder station.
3) Existing population data for the surrounding area (see Item 4 under Scope of Work).
4) Copy of predictive aspects section of COMAH safety report for Bethnal Green gas holder station.

1.3 Structure of Report

Section 2 considers the proposed development in the context of the existing local environment. In particular, it identifies the land uses around the gas holder site, and sets out the population types within the area. Section 3 then describes the way in which HSE consider planning applications in the vicinity of Major Hazard sites, and the particular relevance of HSE's methodology to the proposal.

The detailed quantified risk assessment is given in Section 4, where it is compared with assessments both from HSE and from National Grid. The results of the QRA are then set into context in Section 5, where their implications in relation to the development are discussed. Conclusions are drawn out in Section 6, and background information and analyses are given in the appendices.

2. THE PROPOSED DEVELOPMENT IN CONTEXT

2.1 The Development at The Oval

The four gas holders at National Grid's Bethnal Green site occupy an area of around 150m x 150m. Immediately to the east of this site is a road called The Oval, and the proposed development is at numbers 33-37, backing onto the gas holder site, approximately between Gas Holder 2 and Gas Holder 5. The development area covers around 22m x 25.5m (0.056 ha), and is shown in Figure 2.1. The current stage of the construction (as at 16.06.07) is shown in the photograph in Figure 2.2. The development is also shown in the context of the gas holders and the wider area in Figure 2.3, which also includes HSE's planning zones (see Section 3).

The ground floor of the development will comprise 3 B1 (office/industrial) units. The remaining 4 floors of this 5 storey development will provide 14 residential units: 6 x 1 bedroom, 6 x 2 bedroom & 2 x 3 bedroom, with a likely maximum residential population of around 46 persons. The three B1 units could potentially contain a further 16 people, but only during office hours. It is understood that this development will replace a single storey light industrial unit with an occupancy of around 10 employees.

2.2 Existing Residential Developments

The area around the Bethnal Green gas holders is densely populated, with typical residential population densities of around 200 people / ha. Although there are no very tall buildings, much of the existing housing stock is high rise (typically 5-6 storey) since land is at a premium in this area of East London. It is also noted that a considerable amount of urban regeneration has taken place in the last few decades, in many cases making use of land which had been left derelict since the destruction which took place during the Second World War.

Tower Hamlets Council has provided detailed residential population data based upon the 2001 census. This is given on a ward-by-ward basis, and the information is presented in Appendix A. This shows that there are around 12,600 residents within 500m of the gas holder station. Information drawn from this appendix has been used within the RiskTool model to determine the Societal Risk associated with the gas holder site (see Section 4).

Whilst much of the residential population is separated from the gas holder site by the various industrial and commercial units, there are exceptions. In particular, it is noted that the old Council Depot to the north of the site has been redeveloped, and that housing now exists along the extended Wharf Place right up to the National Grid site boundary.

2.3 Existing Industrial and Commercial Developments

Although the area within 500m of the gas holder station is primarily residential, it also includes industrial, commercial and retail units. For example, review of the population data in Appendix A shows that there are some areas within which the population density is extremely low for this densely populated area. This is at least partly accounted for by the presence of industrial and commercial units adjoining the eastern, southern and western boundaries of the National Grid site.

In addition to the gasholder site, other relevant sites have been identified from the local map, and the non - residential (employee) population information has also been included (to be applied only during normal office hours) in the Societal Risk calculations.

2.4 Sensitive Populations

There are also some facilities within the area which are provided for specific community use. These include:

- schools
- hospitals
- day centres
- surgeries
- nurseries

Such facilities are likely to be used either by large numbers of people, or by more sensitive populations (e.g. the elderly or the very young). They have therefore been identified separately in Appendix A, and this sensitive population information has also been included in the Societal Risk calculations. For hospitals, the populations have been included for 24 hours per day (as for the residential population); for all other cases they have been included only during normal office hours.

It is noted in particular that there are two such facilities which are close to the gas holder site, both adjoining Marian Place, to the west of the site:

- St Peter's North Community Centre
- Pritchard Road Day Centre

3. THE HSE LAND USE PLANNING SYSTEM

3.1 Summary of Land Use Planning Methodology

In order to understand how the land use planning system operates, it is important to have a clear understanding of the key terminology.

A ***hazard*** is simply an item of equipment or process which could lead to harm, i.e. it is the thing which presents the risk, such as a fuel tank or pipeline containing a hazardous substance.

A ***risk*** is the chance of specified level of harm occurring, such as the chance of fatality per year.

There are two main types of risk which may be relevant:

The ***individual risk*** is the chance of a particular individual incurring a specified level of harm (e.g. fatality). Individual risks are generally calculated for a hypothetical individual at a particular location, such as a member of a residential population who spends all their time at home, or a worker who spends say 25% of their time at a work location. Individual risks are often quoted in cpm (chances of occurring per million years).

The ***societal risk*** is a more complex measure which reflects the likelihood of numbers of people being affected in a particular event.

The societal risk can be characterised in a number of ways:

f-n pairs – A series of pairs of values for every possible major accident event, each pair giving the frequency (f) of the event and the number (n) of people affected by that event. This approach is rarely presented as there may be hundreds of such pairs.

FN curve – A graph which shows the cumulative frequency (F) of all events that could lead to N or more people being affected. This curve is derived from the basic f-n pairs, but is much easier to interpret.

Expectation Value (EV) or Potential Loss of Life (PLL) – The average number of people affected per year. It corresponds to the sum of the products of the f-n pairs, and is equal to the area under the FN curve. It provides a simple single measure of the societal risk, and is particularly useful in Cost Benefit Analysis (CBA).

Scaled Risk Integral (SRI) – A simple measure of societal risk devised by HSE for considering specific developments, which takes account of the number of people at the development, the risk to which they are exposed, and the area of the development.

The HSE is responsible for providing advice to Local Planning Authorities on proposed developments in the vicinity of major hazard sites in the UK. The HSE uses information provided by the site operators, generally in the Hazardous Substances Consent applications, to define the extents of 3 zones (Inner, Middle and Outer), which correspond to areas of progressively lower levels of risk. HSE's advice is provided through a system known as PADHI (Planning Advice for Developments near Hazardous Installations), and this system has now been disseminated for use by the Local Planning Authorities.

When a planning application is received by the Local Planning Authority (LPA) for a development which falls within the Consultation Distance (which is defined by the outer limit of the Outer Zone), the LPA uses a set of rules to determine the Sensitivity Level (1 to 4) of the proposed development, and then applies the following decision matrix (Table 3.1, reproduced from PADHI) to determine whether or not HSE would advise against the development, depending on sensitivity and location. The sensitivity levels range from the least sensitive, Level 1 (working populations which could easily respond to emergency actions), to the most sensitive, Level 4 (e.g. the elderly or children, who could not easily respond to emergency actions), with some variations to allow for size and density of developments.

Table 3.1 - HSE Decision Matrix for Land Use Planning

Level of Sensitivity	Inner Zone	Middle Zone	Outer Zone
Level 1	Don't Advise Against	Don't Advise Against	Don't Advise Against
Level 2	Advise Against	Don't Advise Against	Don't Advise Against
Level 3	Advise Against	Advise Against	Don't Advise Against
Level 4	Advise Against	Advise Against	Advise Against

It is noted that, although the HSE rules are designed to minimise the number of people exposed, it is possible that they would allow some population types but not others. The main reason for this is related to the 'sensitivity' of the population. For example, although an industrial or commercial development may be allowed within the Inner Zone, this could be deemed acceptable by HSE because:

a.) The personnel affected would only generally be present for around 25-30% of the time.

b.) A workforce would be expected to be subject to regular fire drills, would be able-bodied and would be expected to be able to respond in an emergency

3.2 Major Hazards from Gasholder Site

The gas holder site is capable of storing around 215t of natural gas. It is used for around 6 months of the year (during winter) as a buffer store to smooth out the peaks of demand, in order to match this demand to a reasonably constant supply. The gas holders are filled during the night, and emptied during the day.

Natural gas comprises around 95% methane. Methane is a highly flammable gas, which can also explode if ignited within a congested region, but will more usually burn without any accompanying high overpressures. It is less dense than air, and hence will begin to rise if it is released into the atmosphere. For this reason, it is less likely to ignite than some other materials, such as LPG (propane/butane) which, since it is denser than air, will disperse at ground level.

Whilst the likelihood of a release of gas is relatively low, there is always a chance that corrosion, structural failure, human error or third party activity could lead to an accidental release. The severity of the incident will depend on the size of the breach, which could be anything from a tiny pinhole to catastrophic rupture. The main types of major accident event which could occur at the gas holder site would result from the ignition of a flammable release and are:

Fireball – If a large release of gas is ignited within a few seconds then a large fireball lasting 10 to 15 seconds may be produced, with very high levels of thermal radiation in all directions.

Jet Fire – Any ignition of gas will burn back to the point of release and may form a jet fire if the release is under pressure. Depending on the nature of the failure, the jet fire may be directed horizontally or vertically. Jet fires continue to burn for as long as the release of gas is not isolated, and the prolonged thermal radiation (or flame impingement) can lead to significant risks, although the impact tends to be relatively local.

Flash Fire – If a release of gas is not ignited within a few seconds of the release, then a cloud of gas will disperse downwind some distance from the point of release. If this cloud then finds a source of ignition, the area covered by the vapour cloud will burn rapidly as a flash fire, with significant risks to all those within the flash fire envelope. The flash fire would probably be followed by a jet fire.

Vapour Cloud Explosion – This is similar to a flash fire, except that, if the vapour cloud is in a partially confined area, then the ignition of the cloud could also lead to a vapour cloud explosion (VCE), generating significant levels of blast overpressure, which would present a risk to people beyond the flash fire envelope.

For the gas holder site, the main concern is a major fireball following catastrophic vessel failure, but lesser events, such as flash fires and VCEs, could also have off-site impact. Jet fires tend to be more local in their effects. Since any release from the gas holder will be at low pressure, the 'jet fire' type event will not have significant momentum, and in many cases would form a vertical wall of flame around part of the circumference of the gas holder, described in this assessment as a seal fire. Also, as noted above, the buoyancy of the natural gas will make it less likely to ignite downwind, and this effect has been accounted for in the QRA modelling.

Most credible fire events are relatively limited in extent (see Section 4). However, the worst case events, fireballs which could involve the complete contents of a single gas holder (i.e. up to 92t), can cause significant damage and potential fatality for distances of order hundreds of metres. It is the inclusion of such events, previously considered as 'incredible', which has caused HSE to increase their Consultation Distance at this site from 60m to around 300m.

3.3 Application of PADHI to Proposed Development

The primary risk which has been identified at the site is a fireball, either from a complete holder collapse (100% of holder contents involved), or from a decoupled seal (50% of holder contents involved). In practice, the decoupled seal events are taken by HSE to define the land use planning zones since complete holder collapse events are much less likely.

A fireball could occur as the result of the immediate ignition of a large volume of gas released to the atmosphere. For the quantities of gas within the Bethnal Green gas holders, the fireball radius (FBR) is of order 100m, and the duration of the event is around 15 seconds. The effects of a fireball are as follows:

a) Within the FBR, there is a high probability that anyone exposed, either outdoors or indoors, could become a fatality. This is taken as the boundary of the Inner Zone.

b) The next level of hazard relates to a normal person exposed outdoors receiving a 'Dangerous Dose', which is a combination of thermal radiation (I, in units of kW/m^2)

and exposure time (t, seconds) such that $I^{4/3}t$ = 1000 thermal dose units (tdu). This is taken as the boundary of the Middle Zone.

c) The final level of hazard relates to a sensitive person exposed outdoors receiving a 'Sensitive Dose', which is set at $I^{4/3}t$ = 500 thermal dose units (tdu). This is taken as the boundary of the Outer Zone.

The use of the PADHI matrix shown in Table 3.1 then requires an assessment of the sensitivity category of the development. From the PADHI sensitivity table (see excerpt in Appendix B), it can be seen that up to 30 units of housing would be considered to be Sensitivity Level 2 (DT2.1). There is an exception, however, such that the housing density should not exceed 40 units/ha. In this case, there are 14 units in an area of 0.056ha, which gives a density of around 250 units/ha, and therefore moves the development into Sensitivity Level 3 (DT2.1X3). From Table 3.1, it can be seen that this would be allowed within the Outer Zone, but would not be allowed within the Middle or Inner Zones.

The Inner Zone extends to around 100m from the centres of the gas holders, and, as can be seen in Figure 2.3, the proposed development is completely covered by this zone. It is also noted that the earlier HSE assessments gave a Consultation Distance of 60m from the edge of the larger gas holders. In either case, the HSE screening tool would provide an initial 'Advise Against' decision.

As an alternative to the above hazard-based approach, HSE also use the concept of Dangerous Dose, which is sometimes taken to represent a probability of fatality of around 1% for an average population, but is generally taken to correspond to a level of harm which would cause:-

- Severe distress to almost everyone.
- A substantial fraction of the exposed population needing medical attention.
- Some people to be seriously injured, requiring prolonged treatment.
- Any highly susceptible people possibly being killed.

When HSE use this concept, they determine the risk to an individual of receiving a Dangerous Dose or more of whatever harm is being considered. The Inner Zone is then set at 10cpm of exceeding the Dangerous Dose, the Middle Zone at 1cpm, and the Outer Zone at 0.3cpm. It is noted, however, that Societal Risk calculations are generally based on the risk of fatality.

4. ASSESSMENT OF RISKS FROM GASHOLDER SITE

4.1 Site Description

National Grid's Bethnal Green gas holder site occupies an area of around 150m x 150m to the SW of Regents Canal in the northern part of the borough of Tower Hamlets. It includes 4 gas holders of the cup and grip water seal type, each of which consists of a series of co-axial cylinders which are able to rise and fall depending on the quantity of gas to be stored. Each cylinder is sealed against the next one by a series of water-filled troughs which are replenished as each seal drops back into the bottom cylinder, which acts as a reservoir. The details of the gas holders are as follows:

- No 1	4 lifts	26 t capacity
- No 2	2 lifts	19 t capacity
- No 4	3 lifts	78 t capacity

- No 5   3 lifts   92 t capacity

The typical operational profile for a gas holder is as follows. Gas holders are not used for 5-6 months in a year so they are at minimum stock level. The gasholders are in operation for 6-7 months in the year and the normal operating model is that the gasholders are filled and emptied on a diurnal cycle; they are filled from approximately 22.00 hours to 06.00 hours and emptied from 06.00 hours to 22.00 hours.

In addition to the gas holders, there is pipework connecting this storage to the main gas network. Most of this pipework is 36” diameter and is buried, although there are some smaller sections of 24” and 30” diameter above ground. There is around 600m of pipework on the site above and below ground, together with a number of valves. These valves are mostly situated to the west of the site. Indeed, the closest approach of any overground pipework to the site boundary adjacent to the development at 33 - 37 The Oval is around 70m. The gas holders and much of the pipework are at low pressure, although there is some of the distribution pipework which is up to around 7 bar.

4.2 Existing Assessments

4.2.1 HSE

The assessment undertaken by HSE is based upon their standard methodology as described in Section 3.3. The reasons for using the specific event (decoupled seal resulting in fireball involving 50% of maximum contents) as a basis for setting the zones are based upon a recent review of gas holder accident statistics. This review identified a number of such large ignited events in the early part of the 20th century, and used these to demonstrate that such events were credible enough to form the basis of the Land Use Planning Zones.

It should be noted that HSE’s assessment on this basis primarily considers ‘credible’ consequences, and does not constitute a complete Quantified Risk Assessment (QRA); in order to do so, it would have to include some of the lesser events which have higher frequencies but shorter hazard ranges. Whilst this would not affect the planning zones significantly, inclusion of such events is relevant to the risk at locations close to the gas holders, such as the development under consideration at The Oval.

In summary, therefore, it is emphasised that the HSE assessment is primarily a high-level screening tool which allows simplified and consistent responses to be made to individual planning cases.

4.2.2 National Grid COMAH Report

Since the site has potential hazardous storage which exceeds the COMAH threshold, a Safety Report, demonstrating that the risks are being managed to a level which is As Low As Reasonably Practicable (ALARP), has been produced by the operator, National Grid. This document includes a section on ‘Hazard Information’, which identifies possible accidental events, and provides estimates of the effects of such events. A copy of the relevant section (Section 4), together with the hazard range contours from Appendix 5, was supplied by National Grid in order to assist with this assessment.

The events considered are:

- Split in 750mm medium pressure pipework
- Release through water tank seal

- Cup and grip seal failure
- Fracture of 750mm pipework
- Fracture of 600mm pipeline
- Decouplement
- Total loss of inventory of gas holder
- Gasholder internal explosion (Split Crown explosion)
- Release of gas holder water
- Firewater runoff

The last two of these were included in order to cover potential environmental effects, and will not be considered in this study. For the remaining cases, calculations were provided, where appropriate, of the dispersion of gas releases in wind speeds of 2, 5 & 10 m/s, so that worst case effects could be identified. Distances to the Lower Flammable Limit (LFL) were given, which showed the hazard ranges for flash fires.

Results for fires were presented in the form of distance to the following effects:

- 1000 tdu, representing serious injury or 1% fatality probability
- 1 kW/m^2, representing minor burn injury (skin blistering)
- 15 kW/m^2, representing piloted ignition of wood

Results for explosions were presented in the form of distances to the following effects:

- 40 mbar, representing 90% window glass breakage
- 200 mbar, representing serious structural damage to buildings

The greatest hazard ranges occur for total loss of inventory of gas holder, for which minor burn injury distances ranged from 320m for Gas Holder 2 to 580m for Gas Holder 5. These are closely followed by the hazard ranges for decouplement, for which minor burn injury distances ranged from 250m for Gas Holder 1 to 350m for Gas Holder 5. (Gas holder 2, containing only 2 lifts, was not considered to be capable of decouplement.) The cup and grip seal failure events gave minor burn injury distances which ranged from 71m for Gas Holder 1 to 90m for Gas Holder 5. The release through water tank seal events gave minor burn injury distances of around 40 - 60m.

The greatest hazard ranges for releases from pipework are a dispersion distance of 77m (flash fire distance), and 57m for minor burn injury, both associated with the fracture of 750mm pipework. The gasholder internal explosion events gave hazard ranges for 90% window glass breakage which ranged from 120m for Gas Holder 2 to 205m for Gas Holder 4.

The information which was supplied did not include any estimates either of the frequency of these events, nor of their severity (i.e. number of people affected). Both these issues are important in the present context, since most of the large hazard range events would have extremely low frequencies. In addition to this, the ranges of many of the smaller events would either not extend beyond the gas holder site, or would only affect small numbers of people occupying nearby industrial premises.

4.2.3 Institution of Gas Engineers

Whilst not an assessment which is specific to this site, the Institute of Gas Engineers and Managers has produced a publication (Reference 1) which provides safety recommendations in relation to developments around gas holder sites. These set a distance of 18m within which buildings would not normally be allowed, on the basis that gas released from minor leaks on the gas holder seals could be drawn into any building within this distance and reach an ignition source. This rule of thumb is based upon calculation of the dispersion of gas from typical seal leaks in a range of credible wind speeds.

For example, it is found that the lighter-than-air methane will rise at low to moderate wind speeds, and is only likely to affect low level locations beyond 18m in high wind speed conditions which are relatively rare. The 18m value is derived from the dispersion calculations for a 5m/s wind in neutral (D stability) conditions, which is generally typical for prevailing winds in the UK (see Section 4.4.2).

4.3 Hazard Identification/Screening

The National Grid COMAH Report for the Bethnal Green site (Reference 2), along with the HSE Safety Report Assessment Guide for Methane Gas Holders (Reference 3), have been reviewed as part of the Hazard Identification process. The following represents a complete list of generic gas holder hazards, which have been identified within either of these reports;

- Catastrophic gas holder failure - 100% contents into fire ball / flash fire
- Split crown accident - 100% contents into fire ball / flash fire
- Decoupled lift - 50% contents into fire ball / flash fire
- Water seal failure over 10m - seal fire / flash fire
- Waterless seal failure - internal explosion
- Puncture of holder, 1m diameter - wall fire / flash fire
- Overfill - ignited flare
- Filling/export line failure at worst case locations
- Pipeline rupture - fireball / jet fire / flash fire / Vapour Cloud Explosion (VCE)
- Pipeline puncture - fireball / jet fire / flash fire / VCE
- Pipeline small leak - jet fire / flash fire
- Pressure regulator failure – VCE

Of the list of generic hazards above, a number of hazards are not considered to be credible at the Bethnal Green site. These hazards omitted from this QRA have been identified in Table 4.1 below along with a justification for their exclusion.

Table 4.1 - Hazards excluded from consideration within this study

Hazard description	Justification for exclusion of hazard
Catastrophic holder failure / Decoupled lift - flash fire	The density of methane (and hence its buoyancy) is such that any instantaneous release of a large volume would rise at such a rate as to clear the dispersing cloud of any potential delayed ignition source. (Note that instantaneous ignition is considered with the fireball event, and the consequences of any other ignited release would be bounded by that event).
Split crown - flash fire	Split crown events are caused by over extraction of gas from the holders, which creates abnormal stresses on the domed head of the holder in a near empty scenario. In this instance it is hard to envisage a release of a significant volume of methane from the gas holder.
Waterless seal failure - internal explosion	The gas holders in question are water sealed.
1m diameter puncture of holder wall	The causes of such an event are considered extremely unlikely. The holders are protected by concrete bollards and the perimeter of the site is fenced off from public access. Catastrophic failure of the holders has been considered to account for failure by earthquakes, aeroplane collision etc. Note that the National Grid COMAH document for the Bethnal Green site has also omitted this event.
Pipeline puncture - fireball / jet fire / flash fire / VCE	For the purpose of Location Specific Individual Risk calculations, these events are bounded by the rupture of the 30" diameter pipework at the worst case location.
Pipeline small leak - jet fire / flash fire	For the purpose of Location Specific Individual Risk calculations, these events are bounded by the rupture of the 30" diameter pipework at the worst case location.
Pressure regulator failure – VCE	For the purpose of Location Specific Individual Risk calculations, these events are bounded by the rupture of the 30" diameter pipework at the worst case location.
Decouplement of Gas Holder No. 2 only	This gas holder comprises two lifts which makes decouplement highly unlikely. Note that this is consistent with the National Grid COMAH document for the Bethnal Green site.

The list of hazards considered within this Quantitative Risk Assessment is therefore:

- Catastrophic failure - fireball
- Split crown - VCE
- Decouplement of lifts - fireball
- Water seal failure - seal fire
- Water seal failure - flash fire
- Overfill jet fire
- Pipework rupture - flash fire
- Pipework rupture - VCE

- Pipework rupture - jet fire

4.4 QRA input data

The following is a summary of the key inputs into the Atkins Quantitative Risk Assessment software RiskTool, which has been used for many similar assessments, and has also been used in some recent studies for HSE.

4.4.1 Population Information

The population data supplied by Tower Hamlets are given in Appendix A. These are used in the RiskTool modelling in different ways, depending upon the amount of time particular groups are likely to be present. For example, it is assumed, as a worst case, that the residential population will be present for 100% of the time, whereas the employee population will only be present during the working day. The major hazard events which have been modelled may also have different effects depending on whether the persons affected are indoors or outdoors. The risk modelling takes this into account, and assumes the following:

Table 4.2 - Assumptions on population locations

Time Period	Indoor	Outdoor
Day time	90%	10%
Night time	99%	1%

The situation for sensitive populations is not so simple. For example, schools and day centres will only generally be occupied during the day, whereas any hospital / care institutions would be occupied 24 hours per day. The only such facility considered in Appendix A is St Joseph's Hospice, for which the 'residential' assumption is used. All other sensitive locations identified will be treated in the same way as for the employee population, and will be considered to be present only during the day time.

4.4.2 Weather data

Some of the events identified involve the dispersion of gas released from pipework, or from the gas holders. The consequences of such releases will depend upon the wind speed and direction, and dispersion modelling has been undertaken for typical and worst case conditions. These are F2, D5 and D8 conditions, where the notation, which is standard in this context, is:

F - Stable conditions (light wind, little mixing)
D - Neutral conditions (higher wind, turbulent mixing)
2 - Wind speed = 2 m/s
5 - Wind speed = 5 m/s
8 - Wind speed = 8 m/s

The low wind speed (F2) is chosen since it normally represents a worst case, in which the mixing is suppressed. In this case, any gas released will rise because of the buoyancy effects, but could become deflected back towards ground level (where it is more likely to encounter an ignition source) in higher wind speeds; hence the use of the extra D8 weather category.

Wind directional probabilities are taken from Heathrow Airport data, and are shown in Table 4.3 below. The direction represents that from which the wind is blowing.

Table 4.3 - Wind directional probability

Wind Direction (° from N)	341 - 10	11-40	41 - 70	71-100	101-130	131-160	161-190
Probability (%)	7.57	9.50	6.24	4.99	3.87	3.54	8.26

Wind Direction (° from N)	191-220	221-250	251-280	281-310	311-340	Calm	Total
Probability (%)	15.04	13.39	10.97	7.22	7.12	2.26	99.97

The probabilities associated with the wind speed conditions identified above are:

F2 - 20%

D5 - 79%

D8 - 1%

It is noted that the National Grid COMAH document uses D10 as the high wind speed condition. However, since analysis of the Heathrow data indicated that such high values were of extremely low probability, the D8 category was chosen on the basis that it would be expected for around 1% of the time.

4.4.3 Harm criteria

This QRA has been undertaken to determine the risk of fatality to people either indoors or outdoors. The criteria applied depend on the type of effect and the type of event, and there is also some allowance made for the protection afforded by being indoors. These criteria are set out for the various event types below.

Risks of fatality have been calculated using probit equations (Reference 5), which relate the dose received to the probability of a particular level of harm, such as fatality. The probit is a non-dimensional number which relates to a specific probability of fatality via the Normal Probability Distribution, as shown in Table 4.4.

Table 4.4 - Relationship between probit and fatality probability

Probit	Probability of Fatality
2.67	1%
5.00	50%
7.33	99%

The precise relationship between the probit Y and probability is defined by:

$$Probability = \frac{1}{\sqrt{2\pi}} \int_{u=-\infty}^{u=Y-5} \exp\left(-\frac{u^2}{2}\right) du$$

where u is an integration variable.

Explosion

The blast overpressure and impulse effects associated with vapour cloud explosion events have the potential to cause injury/fatality to building occupants by:

- causing building collapse;
- generating missiles which impact the occupants; or
- propelling occupants against structures.

To predict the probability of occupant fatality due to explosion effects, vulnerability curves are presented in Reference 4. These curves depict the relationship between the peak side-on blast overpressure and the probability of occupant fatality for 4 different building types:

1 - Hardened structure building: special construction, no windows.

2 - Typical office block: four storey, concrete frame and roof, brick block wall panels.

3 - Typical domestic building: two storey, brick walls, timber floors.

4 - ‘Portacabin’ type timber construction, single storey.

The curve chosen (Curve 2) is considered to be representative for the proposed development, as can be seen from Figure 2.2.

For those personnel outdoors, a probit relationship is used to estimate the probability fatality resulting from the predicted level of blast overpressure. The probit implemented into RiskTool is:

Probit = 1.47 + 1.35 ln(P), where : P = overpressure (psi)

Fireball, jet fire, seal fires

Scenarios involving the release and ignition of flammable substances have the potential to cause fatalities by exposing individuals to high thermal radiation “dose” levels.

For fireballs, a probit relationship (Reference 6) is used to estimate the probability of fatality resulting from the predicted thermal dose indoors. The probit implemented in RiskTool is:

Probit = -14.9 + 2.56 ln(tdu)

where :

tdu = 3150 R^2/x^2 -150 (Reference 7)

R = fireball radius (m)

x = distance from fireball (m)

For jet fires, the probability of fatality indoors is assumed to relate to the thermal radiation level outdoors (I) according to the following criteria (Reference 8) :

I > 25.6 kW/m^2 outdoors	implies 100% fatality indoors
14.7 < I < 25.6 kW/m^2 outdoors	implies the same fatality probability as outdoors (i.e. people indoors would try to escape)
I < 14.7 kW/m^2 outdoors	implies 0% fatality indoors

For those personnel not located in buildings, the same thermal dose response probit relationship is used to predict the probability of fatality from all thermal radiation effects. However, in this case, the outdoor thermal dose is used ($tdu=I^{4/3} \times t$) (Reference 9).

An exposure time (t) is required in order for the probability of fatality to be derived, and this is an output only from the fireball model. However, for this assessment an exposure time for the effects of jet fires of 20 seconds is used for persons located outdoors, after which time it is assumed that they will have escaped to a place of safety (Reference 10).

Flash fires

In general, flash fires only present a hazard to those personnel trapped or located within the flammable envelope of the cloud, although flame penetration may also occur through open or failed windows and doors. For people adjacent to a window, it is reasonable to assume that the effects of flame penetration will be the same as if they were outside. For people not adjacent to windows, the direct effects of flame penetration are not so easily defined.

Even if flame penetration does not occur, occupants may be exposed to heat radiated through windows. The resulting thermal dose may be sufficiently high to cause 50% fatality for an average population adjacent to the window, although the thermal dose drops significantly (equivalent to less than 1% fatality at 0.7 m) away from the window (Reference 11).

In the event of a flash fire, approximately 5% of those who are sheltered by typical domestic housing will be fatalities as a result of secondary fires (Reference 9). Based on the above discussion, the probability of fatality indoors, within the outdoor LFL envelope, is taken to be 10% (best estimate).

For those persons located outdoors, it is assumed that if they are located within the potential envelope of the un-ignited cloud (i.e. the area covered by the LFL), then the probability of fatality is 1 in the event of ignition (Reference 12).

Dangerous Dose criteria

Risk calculations have also been undertaken using the 'Dangerous Dose' concept, for direct comparison with the way in which HSE set the planning zones (see Section 3.3). The criteria used for this part of the assessment are given below:

	Outdoor	**Indoor**
Fireballs	1000 tdu	1000tdu

VCEs from holders	140 mbar	140 mbar
Seal fires and jet fires	1000 tdu	1000 tdu
Flash fires	100% in cloud envelope	0% in cloud envelope

4.5 Consequences of Major Hazard Events

This section represents a summary of the manner in which the major hazards have been modelled in order to determine their consequences.

The Quantitative Risk Assessment carried out has been based on a limited amount of available site data. In a small number of instances, where site data have been insufficient to determine hazard consequences, the consequence results of the National Grid COMAH study have been replicated within this report by adjusting modelling inputs. Below is a summary of the data which have been obtained in this manner;

1. The release rate from seal leaks has been taken as 1.35m^3/s per metre of water seal (as per Reference 13).
2. The release rate from pipework ruptures has been matched to National Grid dispersion results to give 15 kg/s from a rupture of the 30" line. Note that the 36" pipe line at the site is buried beneath the ground.
3. The overpressures created by split crown VCE events have been calculated using 1.5% of the volume of the gas holder maximum working capacity. This value has been taken based upon matching the 'distance to overpressure' results presented by the National Grid.

For consequences which depend on the wind, the conditions used have been taken as F2, D5, D8 (see Section 4.4.2).

4.5.1 Fire Modelling

Fireballs

For the purposes of this study, the fireball resulting from a catastrophic failure being ignited immediately has been assumed to involve the full contents of the gas holder (50% for decouplement events). The fireball has been assumed to be just touching the ground and to have a diameter (D) given in terms of the mass of fuel M_F (kg) (Reference 14) by:

$D = 5.8\ M_F^{1/3}$ (metres)

The fireball duration (T) in seconds is given as (Reference 15):

$T = 0.45\ M_F^{1/3}$ for $M_F < 37{,}000$ kg

$T = 2.59\ M_F^{1/6}$ for $M_F > 37{,}000$ kg

The level of thermal radiation has been based on the solid flame model as described by Crossthwaite (Reference 7). The thermal radiation is given by:

$I = F\ E\ t_a$

where:

I = Thermal radiation intensity (kW/m^2)

F = View Factor

E = Surface emissive power (kW/m^2).

t_a = Atmospheric transmissivity, taken as 1 – 0.0565 ln(x – R) for x>R+1

x = Horizontal distance between receptor and fireball centre (m)

R = Fireball radius (m)

Flash fires

For flash fires, dispersion to the Lower Flammable Limit values has been modelled using the HGSYSTEM HEGADAS-S code within CIRRUS, with a surface roughness of 0.3m to represent the suburban environment.

The consequences of flash fires are calculated in terms of the flammable gas concentration versus distance, with the length of the region covered by the flash fire taken to be the distance to the Lower Flammable Limit. Within the modelling, the effects of flash fires are represented as a step function; i.e. the probability of fatality outdoors within the cloud area is one, whereas outside the cloud area it is zero. No account has therefore been taken of any distance/heat radiation decay relationships when assessing flash fire hazards. For indoor populations, the probability of fatality is 10% within the LFL envelope, and 0% outside of this boundary.

Jet fires

Jet fires have been modelled using the SHELL Chamberlain Jet Flame Model which has been coded within the Atkins RiskTool computer code.

Seal fires

Thermal radiation from seal fires has been modelled using a simple ‘point source’ model. Modelling has assumed a release rate of 1.35m^3/s per meter of water seal (as per Reference 13). A value of 0.3 has been taken as the proportion of the heat of combustion emitted from the fire.

4.5.2 Explosion Modelling

Vapour cloud explosions

The consequences of vapour cloud explosions have been modelled using the TNO ‘Multi-Energy’ model (Reference 16), with explosion strength 7. The overpressure effects from the explosion are determined by the material involved in the explosion and the volume of the gas cloud. This volume has been estimated on the basis of the lateral and vertical extent of flammable clouds suggested by dispersion modelling, and by the estimated volume of nearby congested plant areas where build-up of gas is possible, as follows:

> For VCE from a pipeline release, the combustible volume was calculated based upon site drawings, and estimation of the volume of congested areas close to the source of the leak (between the ‘valve room’, ‘MEG storage tank’ and Gas Holder 4. The stoichiometric mixture of the cloud of air/methane was then used in explosion calculations. Where the estimated flammable cloud volume was less than the maximum congested volume, the calculated lower value was used in the explosion modelling.

Split crown explosions

The overpressures created by split crown VCE events have been calculated using a 1.5% volume of the gas holder maximum working capacity. This value has been taken based upon a back calculation from the 'distance to overpressure' results presented within the National Grid COMAH report.

4.6 Frequencies of Major Hazard Events

Base event frequencies

The base case frequencies for the hazards considered are summarised below. These frequencies relate to the unignited releases, except where otherwise indicated. The probability of ignition for the various events is described later in this section.

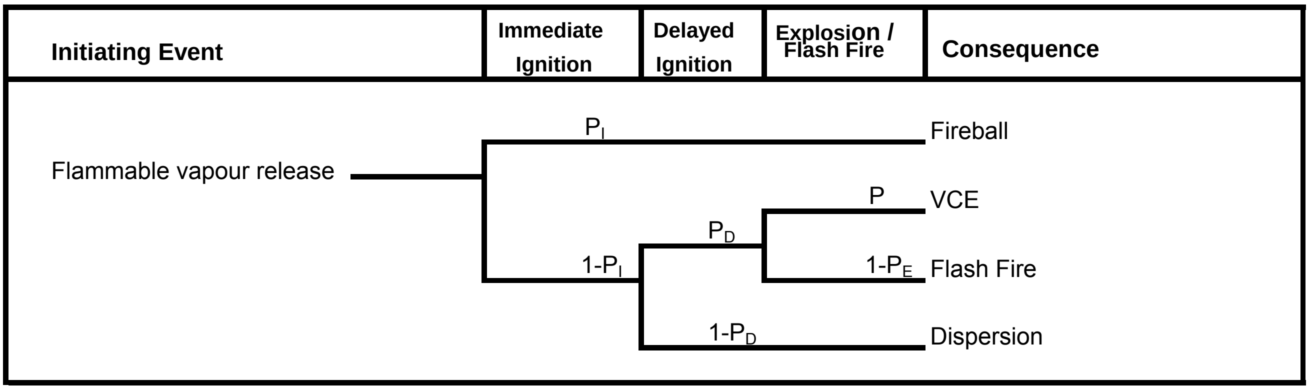
Table 4.5 - Initiating event frequencies used in QRA

ID	Initiating event	Frequency (/ holder / yr)	Reference for initiating frequency
a	Catastrophic vessel failure	2.00E-06 +	Appendix C Table C7
b	Split crown event	1.00E-06 +	See 'Ignition probabilities' section below
c	Decouplement of lifts	2.00E-05 +	Appendix C Table C7
d	Seal failure	1.40E-03	Appendix C Table C5
e	Overfill event	5.60E-04	Appendix C Table C5
f	Pipework rupture	3.10E-04	Reference 17
g	Pipework major leak	8.47E-03	Reference 17
h	Pipework minor leak	8.08E-02	Reference 17

+ value includes probability of ignition

The following diagram shows a graphical representation of the events which may follow a flammable vapour release. Each branch of this event tree represents a different conditional probability of ignition.

Flammable release event tree



Ignition probabilities

The ignition probabilities for the catastrophic failure and decouplement events (labelled a and c in Table 4.5 above) have already been factored in to the event frequencies calculated from historical data in Appendix C. For the case of a split crown VCE event, an ignited split crown event frequency of 10^{-6} has been used, based upon the re-assessment which HSE has quoted in some of their more recent Panel Papers. For the remaining continuous release events, the ignition probability varies depending upon the release rate. These ignition probabilities have been calculated using Reference 17 and are summarised below in Table 4.6.

Table 4.6 - Ignition probabilities used for continuous releases (Reference 17)

Ignition event	Release rate (kg/s)	Ignition Probability	
		Immediate	Delayed
Gas holder 1 overfill	0.79	4.19E-03	*
Gas holder 2 overfill	0.58	3.98E-03	*
Gas holder 4 overfill	2.35	5.05E-03	*
Gas holder 5 overfill	2.84	5.21E-03	*
Gas holder 1,2,4,5 seal fail	9.20	6.42E-03	5.97E-02
30" pipe release	15.00	6.92E-03	8.07E-02

* All such events considered to be immediate ignition

Wind direction

Historical data taken from Heathrow airport weather station have been used to determine the probability of the wind blowing from various sectors of the wind rose. These data are represented in Table 4.3 above.

Seal fire probability

Seal fires could occur at any point on the circumference of the gas holders. In order to keep the total number of events modelled in RiskTool manageable, each gas holder has been divided into 4 quadrants, and the seal fire probability split equally between each location. For offsite risk determination, not all of these points on the circumference of each holder will radiate outwards from the gas holder site in the case of a seal fire. Therefore the quadrants have been arranged using site plans to ensure that the offsite effects (in particular those at the development site, and at other nearby densely populated sites) are realistically and conservatively modelled.

4.7 Overall Risk Assessment

4.7.1 Presentation of results

The following is a summary of the frequency and consequence data used in the Quantitative Risk Assessment (Table 4.7).

Table 4.7 - Summary of Frequency and Consequence Data for all hazards analysed

Vessel	Event	Frequency with ignition (/yr)	Consequence criterion & units	Approx hazard range to criterion (m)
GH1	Catastrophic failure fireball	2.00E-07	FB radius	82.0
GH1	Decouplement fireball	2.00E-06	FB radius	65.0
GH1	Seal failure seal fire	6.75E-06	1000 tdu	23.0
GH1	Overfill jet fire	2.35E-06	1000 tdu	31.0
GH2	Catastrophic failure fireball	2.00E-07	FB radius	74.0
GH2	Seal failure seal fire	6.75E-06	1000 tdu	23.0
GH2	Overfill jet fire	2.23E-06	1000 tdu	28.0
GH4	Catastrophic failure fireball	2.00E-07	FB radius	118.0
GH4	Decouplement fireball	2.00E-06	FB radius	94.0
GH4	Seal failure seal fire	6.75E-06	1000 tdu	23.0
GH4	Overfill jet fire	2.83E-06	1000 tdu	44.0
GH5	Catastrophic failure fireball	2.00E-07	FB radius	126.0
GH5	Decouplement fireball	2.00E-06	FB radius	100.0
GH5	Seal failure seal fire	6.75E-06	1000 tdu	45.0
GH5	Overfill jet fire	2.92E-06	1000 tdu	30.0
30"	Pipework rupture jet fire	2.14E-06	1000 tdu	107.0
GH1	Split crown VCE	1.00E-06	200 mbar	44.0
GH2	Split crown VCE	1.00E-06	200 mbar	39.0
GH4	Split crown VCE	1.00E-06	200 mbar	60.0
GH5	Split crown VCE	1.00E-06	200 mbar	67.0
30"	Pipework rupture VCE	3.74E-06	200 mbar	60.0
GH1	Seal failure flash fire (F2)	1.12E-05	5% vol	18.6
GH1	Seal failure flash fire (D5)	4.41E-05	5% vol	13.7
GH1	Seal failure flash fire (D8)	5.58E-07	5% vol	11.5
GH2	Seal failure flash fire (F2)	1.12E-05	5% vol	18.6

Vessel	Event	Frequency with ignition (/yr)	Consequence criterion & units	Approx hazard range to criterion (m)
GH2	Seal failure flash fire (D5)	4.41E-05	5% vol	13.7
GH2	Seal failure flash fire (D8)	5.58E-07	5% vol	11.5
GH4	Seal failure flash fire (F2)	1.12E-05	5% vol	18.6
GH4	Seal failure flash fire (D5)	4.41E-05	5% vol	13.7
GH4	Seal failure flash fire (D8)	5.58E-07	5% vol	11.5
GH5	Seal failure flash fire (F2)	1.12E-05	5% vol	18.6
GH5	Seal failure flash fire (D5)	4.41E-05	5% vol	13.7
GH5	Seal failure flash fire (D8)	5.58E-07	5% vol	11.5
30"	Pipework rupture flash fire (F2)	4.24E-07	5% vol	18.6
30"	Pipework rupture flash fire (D5)	1.67E-06	5% vol	13.7
30"	Pipework rupture flash fire (D8)	2.12E-08	5% vol	11.5

The integration of frequencies and consequences from the identified hazards has been conducted using RiskTool. Table 4.8 below gives a summary of the Individual Risk output from the software for the proposed development (nearest & furthest) for a residential population present 100% of the time, and the percentage contribution of each scenario to these risks is also shown. The effective risk for an office worker, present for 25% of the time at the nearest part of the development, will be around 3cpm.

Table 4.8 - Location Specific Individual Risk Results (cpm) at development

Location	Development nearest	Development furthest
Risk	**11.7 [15.4]**	**5.7 [8.9]**
Fireballs	58%	94%
Split crown VCEs	8%	4%
Seal fires	33%	0%
Jet Fires	<1%	<1%
Flash Fires	<1%	0%
Pipework events	1%	1%

Note: Risks quoted are Individual Risk of Fatality; Risks of receiving a Dangerous Dose or more are given in parentheses []

Since there are uncertainties in the modelling, some sensitivity cases have been undertaken. The variants which have been covered are indicated below, and the results are given in Table 4.9:

Increased Fireball Freq	Ignition probability increased from 0.1 to 0.5
Decreased VCE mass %	0.75% holder volume used (instead of 1.50%)
CIA building Category 1 or 3	Instead of CIA building Category 2

.

Table 4.9 - Sensitivity of Individual Risk Results (cpm) at development

Location	Development (nearest)		Development (furthest)	
	Fatality	**Dangerous Dose**	**Fatality**	**Dangerous Dose**
Base Case	**11.7**	**15.4**	**5.8**	**8.9**
Increased Fireball Freq	40.4	51.6	28.4	45.1
Decreased VCE mass%	11.3	15.4	5.6	7.9
CIA building Category 1	10.7	15.4	5.5	8.9
CIA building Category 3	11.9	15.4	6.1	8.9

Estimates of Societal Risk are also given, in the FN curve shown in Figure 4.1.

4.7.2 Robustness of results

Risks have also been calculated on a Dangerous Dose basis (see Section 4.4.3), and the results were found to be broadly consistent with the current HSE planning zones. The sensitivity studies reported in Section 4.7.1 have shown that the predicted ranges on a risk of fatality basis are 11-40 cpm at the western site boundary and 6-28 cpm at the eastern site boundary. The value of 11.7 cpm for the base case ('nearest') is therefore considered to be representative of the actual risk of fatality at the development.

A further consideration is the magnitude of the Societal Risk. The FN Curve in Figure 4.1 lies between the HSE comparison lines, as would be expected for most Top Tier COMAH sites. Indeed, because the FN line is around an order of magnitude below the upper comparison line, the site would not be considered to have a particularly high societal risk. This arises because the area close to the gas holder site is currently primarily occupied by industrial or commercial, rather than residential, premises. Figure 4.1 also includes the FN curve for the pre-development case, identified as 'Pre-Development'.

5. DISCUSSION OF ISSUES

5.1 Individual risk considerations

The individual risk of fatality at 33-37 The Oval is estimated to be around 12 cpm for a typical residential population. This compares with the individual risk of receiving a *dangerous dose* of around 10 cpm (which corresponds to a risk of fatality of around 2-5 cpm) at the inner zone boundary. The results of this assessment are therefore clearly consistent with the screening process which is applied within the PADHI system: i.e. this value is high compared with the level at which HSE would Advise Against for any development containing more than a few people.

It is further noted (see comments below Table 3.1) that the risks to a workforce would be effectively reduced to around 3cpm since any individual would only be present for around 25% of the time. Within certain limits on the numbers of people involved, HSE would therefore not 'Advise Against' such non-residential developments at this location.

5.2 Comparison with other risks

In order to help understand the level of risk at the proposed development, it is worthwhile to compare it with historical data on the other risks to which people are typically exposed. HSE's 'Reducing Risks, Protecting People' document (Reference 18) provides some data on the risks to which people are routinely exposed. Some of this information is reproduced below, in terms of risk of fatality as annual experience per million, or chances per million years (cpm).

Annual risk of death (entire population)	10,309 cpm	(1 in 97)
Annual risk of cancer	2,584 cpm	(1 in 387)
Annual risk from all types of accident	246 cpm	(1 in 4,064)
Annual risk from all forms of road accident	60 cpm	(1 in 16,800)
Construction	59 cpm	(1 in 17,000)
Agriculture, hunting, forestry and fishing	58 cpm	(1 in 17,200)
Manufacturing industry	13 cpm	(1 in 77,000)

These risks can be compared with the additional annual risk for the most exposed people at the proposed development of up to about 12 cpm (once in 50,000 years) due to major accidents. For example, the annual risk of death for the most exposed person would increase by about 0.12% (from 10,309 to 10,321 cpm), and this increase would be less than a twentieth of the risk of dying in all types of accident.

5.3 Levels of Risk and their Acceptability

Based on the results in Section 4.7 it is estimated that the total level of individual risk of fatality for a resident at the new development is around 12 cpm. In order to set this level of risk in the context of typical major hazard risks, it can usefully be compared with standard risk tolerability criteria. The HSE's framework for judging the tolerability of risk is represented in Figure 5.1, and described in paragraphs 122 to 124 of R2P2 as follows:

> *The triangle represents increasing level of 'risk' for a particular hazardous activity (measured by the individual risk and societal concerns it engenders) as we move from the bottom of the triangle towards the top. The dark zone at the top represents an unacceptable region. For practical purposes, a particular risk falling into that region is regarded as unacceptable whatever the level of benefits associated with the activity. Any activity or practice giving rise to risks falling in that region would, as a matter of principle, be ruled out unless the activity or practice can be modified to reduce the degree of risk so that it falls in one of the regions below, or there are exceptional reasons for the activity or practice to be retained.*
>
> *The light zone at the bottom, on the other hand, represents a broadly acceptable region. Risks falling into this region are generally regarded as insignificant and adequately controlled. We, as regulators, would not usually require further action to reduce risks unless reasonably practicable measures are available. The levels of risk characterising this region are comparable to those that people regard as insignificant*

or trivial in their daily lives. They are typical of the risk from activities that are inherently not very hazardous or from hazardous activities that can be, and are, readily controlled to produce very low risks. Nonetheless, we would take into account that duty holders must reduce risks wherever it is reasonably practicable to do so or where the law so requires it.

The zone between the unacceptable and broadly acceptable regions is the tolerable region. Risks in that region are typical of the risks from activities that people are prepared to tolerate in order to secure benefits, in the expectation that:

- *the nature and level of the risks are properly assessed and the results used properly to determine control measures. The assessment of the risks needs to be based on the best available scientific evidence and, where evidence is lacking, on the best available scientific advice;*
- *the residual risks are not unduly high and kept as low as reasonably practicable (the ALARP principle – see Appendix 3 [of R2P2]); and*
- *the risks are periodically reviewed to ensure that they still meet the ALARP criteria, for example, by ascertaining whether further or new control measures need to be introduced to take into account changes over time, such as new knowledge about the risk or the availability of new techniques for reducing or eliminating risks.*

In terms of providing quantitative criteria to define these regions, paragraph 130 of R2P2 states that:

> *"HSE believes that an individual risk of death of one in a million per annum for both workers and the public corresponds to a very low level of risk and should be used as a guideline for the boundary between the broadly acceptable and tolerable regions."*

Paragraph 132 of R2P2 goes on to consider the boundary between the 'tolerable' and 'unacceptable' or intolerable region and concludes:

"For members of the public who have a risk imposed upon them 'in the wider interests of society' this limit is judged to be … 1 in 10,000 per annum".

As the risk of fatality for the most exposed people at the new development is considered to be up to about 12 cpm, or once in 80,000 years, it is reasonable to conclude that the maximum risks at the proposed development are about a factor of 12 times the level which would be regarded as insignificant (broadly acceptable), but a factor of 8 below the level at which they would be regarded as becoming intolerable. They are also rather higher than the levels which HSE would consider appropriate for a development of this nature.

5.4 Societal Risk due to Gasholder Site

In addition to the above individual risks being regarded as significant, it should be remembered that the worst case accident, involving a major fireball, could theoretically result in large numbers of people being affected in a single incident, although the likelihood of such a very severe event is very low (probably of the order of less than once in 120,000 years). This possibility of multiple fatalities may be regarded as a greater concern than the individual risks of around 12 cpm. There are few generally accepted criteria for judging the acceptability of such risks to groups of people, although paragraph 136 of R2P2 states that:

> *"HSE proposes that the risk of an accident causing the death of 50 people or more in a single event should be regarded as intolerable if the frequency is estimated to be more than one in five thousand per annum."*

It is noted that HSE sometimes calculate another measure of societal risk known as the Scaled Risk Integral (SRI), as noted in Paragraphs 3c and 9 of Annex 2, which provides a simple approach which takes account of the most relevant factors. The methodology for calculating the SRI is described by Carter (Reference 19) and Hirst and Carter (Reference 20) as follows:

$$\text{SRI} = \frac{\text{P x R x T}}{\text{A}}$$

Where, P = population factor, defined as $(n + n^2)/2$

n = number of persons at the development

R = average level of individual risk (of exceeding dangerous dose) in cpm

T = proportion of time development is occupied by n persons

A = area of the development in hectares

Taking n = 46 people for 75% of the time and n=62 people (residents + workers) for 25% of the time, R = 12 cpm, and A = 0.056 ha (approximate area), gives:

$$SRI = \frac{(46+46^2)/2\times12\times0.75}{0.056} + \frac{(62+62^2)/2\times12\times0.25}{0.056} = 278{,}400$$

This is only an indicative calculation using maximum numbers of people present. Using a more typical occupancy of 35 people in the residential part of the development gives an SRI of 170,000. Both these results are close to the value of 500,000, above which HSE would consider recommending call-in (see Annex 2, paragraph 3c of R2P2), but they are not sufficiently low that HSE would be unconcerned by the societal risk associated with the development.

Clearly, however, the introduction of up to 62 people at the development will increase the societal risk. This increase can be seen in Figure 4.1, where there is an increase in frequency in the range of 5 - 500 fatalities. The PLL is increased from $2.77\text{x}10^{-3}$ without the development, to $3.67\text{x}10^{-3}$ post-development. It can therefore be seen that the development would increase the PLL by around 32%. It is noted, however, that the post development PLL is still a factor of around 20 below that which applies to the HSE upper comparison limit on Figure 4.1.

5.5 Potential for Risk Reduction

The results presented in Section 4 have shown that the Individual Risk at 33-37 The Oval is calculated to be around 12cpm. It has also been shown that there are significant uncertainties in some of the modelling, but that the prediction is considered to be a cautious best estimate. On the basis of the 'best estimate' modelling, this risk is derived from the following types of event:

Fireball ≈ 60%

Split crown explosion ≈ 10%

Seal fire ≈ 30%

It is noted that the current thinking of HSE (as applied to their Land Use Planning zone derivation) would increase this prediction to around 40cpm, split roughly 90:10 between fireball and seal fire, with a small contribution from explosion.

Since any risk reduction measure which could be applied will depend upon which type of event is to be mitigated against, a brief discussion of the issues associated with each event type is given below:

Fireball **-** This is a short duration but very intense event. The fireballs from the adjacent gas holders are likely to be sufficiently large that they envelop the building. In such cases, there is little which could be done to mitigate the effects.

Explosion - In many cases, the risks from explosions are exacerbated by glass breakage. One potential for mitigation would therefore be to specify high strength or shatter-proof glass. In this case, however, the development is within the range where it is likely that some structural collapse would result, for which the only mitigation would be to provide a 'hardened' type of structure, which is likely to be inappropriate for a residential development.

Seal fire - The effects of thermal radiation from a seal fire will last for rather longer than the tens of seconds expected for a fireball. There is therefore the potential for evacuation, and escape routes should be provided which enable residents to reach a place of safety without being exposed to more radiation than necessary.

Other features of the development which could impact on the risks are:

a.) Use of roof terraces

While there would be no mitigation possible against a fireball, the risk outdoors may not be significantly greater than that indoors. For the explosion event, the risk at a general location outdoors could be slightly reduced (since most of the risk arises from being ***inside*** a building which collapses), although this would at best be a marginal effect for occupants of the roof terraces. In the case of the seal fire, it is possible that terrace occupants could escape indoors, and then evacuate from the building at ground level.

In practice, however, one of the key risk reduction factors is expected to be control of ignition sources close to the gas holder. The terraces at two levels (1^{st} floor and 4^{th} floor) should therefore be considered in relation to controlling ignition sources. Ideally, both should be removed or made inaccessible for normal use. It is recommended that the lower terrace, which is within 18m of the gas holders, is removed; if it is not possible to remove the upper level terrace, then ignition source restrictions should be applied, since there is the potential for a greater travel distance of a flammable cloud at this higher level. This could take the form of appropriate signage advising against smoking and the use of barbeques when the adjacent gas holders are in use (i.e. during the winter months). In view of both the greater distance from the gas holders, and the intervening presence of the building, no similar restrictions need to be applied to any terraces at the front of the building.

b.) Design of boundary wall

The thermal radiation from a fireball originates from a point which is around 100m above ground level. Thus most of the radiation would be downwards and would not be mitigated by a boundary wall. The same would apply for a seal fire, which could occur at any water-seal position. The explosion event will originate from ground level, and in principle its effects could be reduced by appropriate design of a boundary wall. However, the calculations indicate that overpressures of around 930mbar may be expected at the boundary; any wall designed to deflect such a blast would need to be at least half the building height, and is likely to be prohibitively expensive.

It is understood, however that the rear boundary wall will be 5.2m high, and will have no openings. This would ensure that any low level gas releases would be deflected upwards by the presence of this wall as well as by its buoyancy. Moreover, this would be true of all wind conditions, including those higher wind speeds which would otherwise deflect the cloud towards the ground.

c.) Minimising potential for gas ingress

The risk is reduced if any gas released is unable to encounter an ignition source. This can be achieved by minimising the openings facing the gas holders, and ensuring that any which are within 18m are protected, as noted above, by the boundary wall.

d.) Installation of shatter-proof glass

One of the contributors to the risk is explosion. Since much of the injury potential is from flying glass, the effects of explosion can be reduced by ensuring that the glass in any windows facing the gas holders is shatterproof. This can be achieved either through use of specialist glass from a supplier such as Romag, or by application of window film such as Llumar to the internal face of the glazing.

e.) Provision of adequate means of evacuation

In the event of a fire on one of the gas holders, the thermal radiation at the rear of the building is likely to be sufficiently intense that evacuation would be impeded. The building design should therefore ensure that all occupants, including those using the terraces, can be evacuated safely to the front of the building.

Summary of desirable design features:

1) Ensure impermeability of rear wall up to 5m height.

2) Minimise window openings facing gas holders within 18 metres of the holder or where not protected by the rear wall.

3) Specify heat/blast resistant or shatterproof glass for windows facing gas holders.

4) Prevent the use of the lower level rear-facing roof terraces.

5) Display signage restricting the use of ignition sources on the upper level rear-facing roof terraces when gas holders are in use.

6) Ensure adequate provision is made for evacuation to the front of the building in the event of minor fires.

6. SUMMARY AND CONCLUSIONS

The current PADHI system (see Section 3.3) is based upon consideration of individual risk, although HSE is currently considering ways in which they can also address societal risk issues around major hazard installations. As part of their considerations, there is a recent consultative document, CD212 (Reference 21), against which they requested responses from interested parties by 2nd July 2007. This document includes a list of 54 UK sites around which HSE has identified societal risk issues. There are 15 gas holder sites in this list, which includes the Bethnal Green site. CD212 covers a range of issues, including the consideration of the wider context. For example, there is a proposal that HSE may have some input during the preparation of development plans for areas affected by such sites, in order to ensure that any future development is appropriate to the area and to the risks from the major hazard site.

It has been shown in this quantified assessment that the societal risk associated with the Bethnal Green gas holder site is not at present exceptionally high for a typical COMAH site. It has also been shown that the societal risk would not increase to an intolerable level if the proposed development were to be allowed. The primary objection of HSE is therefore likely to be the precedent which this may set in allowing a significant increase in societal risk - for example, the 32% increase from the proposed development would imply that only 3 such developments would be required before the societal risk was almost doubled.

It is therefore clear that, when considering potential individual developments close to major hazard sites, both individual and societal risk need to be considered. In some cases, robust calculations of these risks may show them to be below some ‘broadly acceptable’ level, as defined by HSE. Conversely, they may be shown to be intolerable in all circumstances. Between these levels (as is the case for the proposed development), the acceptability of the risks, either individual or societal, can only be judged by balancing the calculated risks with the socioeconomic benefits (both for the hazardous installation and for developments in the vicinity). Ultimately, although HSE provides advice, it is for the Planning Authority to make such judgements, taking account of factors such as:

- nature and scale of benefits to the local / wider community
- provision of jobs / employment
- contribution to GDP and local taxes
- consistency with local development plans
- views of the public
- etc

and balancing these benefits against the risks in terms of:

- number and likelihood of people affected (fatalities and injuries)
- nature of harm

For example, a gas holder site such as Bethnal Green could be regarded as providing a significant regional benefit in terms of providing a fuel supply to a large community, and hence a planning authority might consider that a moderate level of societal risk associated with the installation was acceptable (provided it could be demonstrated to be ALARP), whilst for a smaller industrial activity with no significant socioeconomic benefits, a planning authority might consider the same level of societal risk to be unacceptable (even if it was also ALARP).

Similarly, where a development is proposed near an existing major hazard site, it is also the responsibility of the planning authority to make such judgements, taking account of the factors noted above. If there was such a pressing need for residential development in the area, and no other land was available, then the Planning Authority may be inclined to grant Planning Permission. In the present situation, however, in view of the relatively high risks, it may be considered to be more appropriate only to allow development of a less sensitive nature, such as light industrial or commercial. It is also noted that, although HSE may advise against this type of residential development anywhere within the Inner Zone, this detailed QRA has shown that the risks drop off quite rapidly away from the Bethnal Green gas holder site, implying that such a development could be more readily justified on other nearby sites, e.g. on the east side of the Oval.

It is therefore concluded that:

1.) The individual risk, at around 12cpm, is not intolerable, but is above the level at which HSE would advise against for this type of development.

2.) The current societal risk associated with the gas holder site is not particularly high for a Top Tier COMAH site.

3.) The addition of the extra population will increase societal risk by around 32%, but it will still remain well within HSE guidelines.

4.) Whilst it is possible that a case could be made for accepting this additional risk, HSE is likely to be concerned at the potential for cumulative societal risk effects if adjacent properties were to be developed in a similar way.

7. REFERENCES

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8. ABBREVIATIONS AND ACRONYMS

ALARP	As Low As Reasonably Practicable
CD	Consultation Distance
CIRRUS	Suite of consequence modelling codes developed by BP
COMAH	Control of Major Accident Hazards
cpm	Chances per million (years)
DTL	Dangerous Toxic Load
EV	Expectation Value
FBR	Fireball Radius
FN	Cumulative frequency of N or more fatalities
HGSYSTEM	Suite of gas dispersion modelling codes
HSE	Health and Safety Executive
LPA	Local Planning Authority
LPG	Liquified Petroleum Gas
LSIR	Location Specific Individual Risk
PADHI	Planning Advice for Developments near Hazardous Installations
PLL	Potential Loss of Life
QRA	Quantified Risk Assessment
R2P2	Reducing Risks, Protecting People (HSE publication, 2001)
SRI	Scaled Risk Integral
tdu	thermal dose units $(kW/m^2)^{4/3}$.seconds
VCE	Vapour Cloud Explosion

Figure 2-1 Plan of the proposed development at 33-37 The Oval

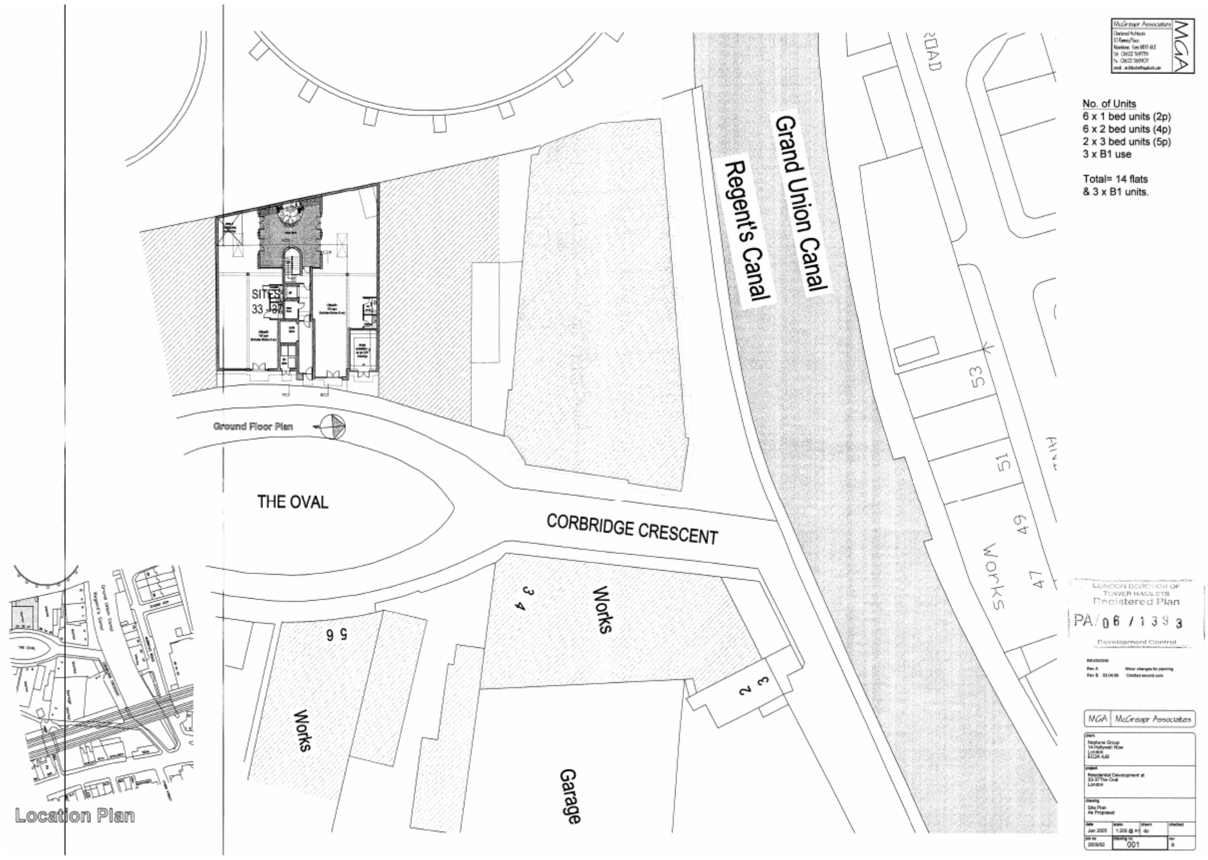


Figure 2-2 Photo showing development at 33 - 37 The Oval and Gas Holder no. 5

Figure 2-3 HSE Consultation Zones

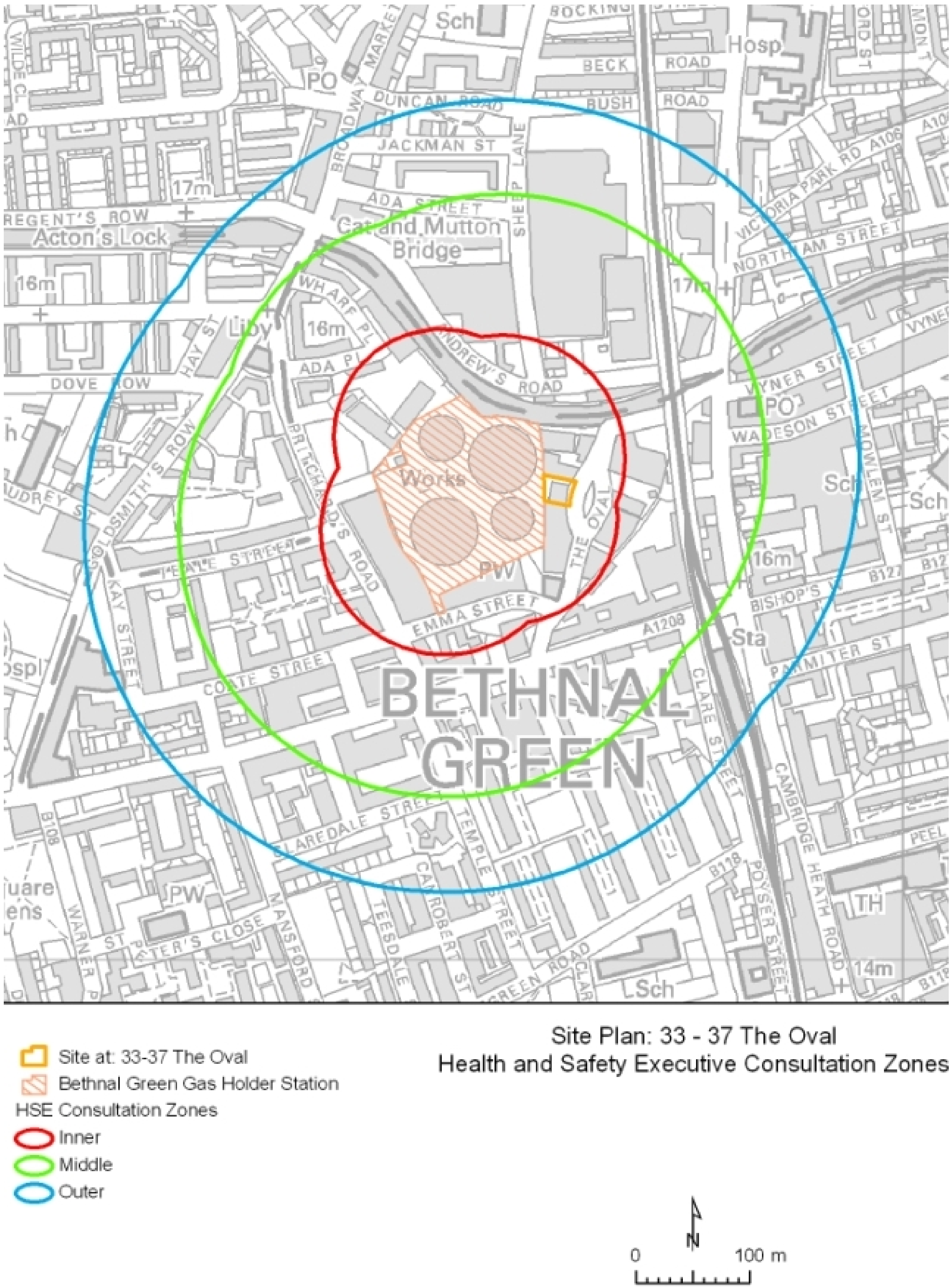


Figure 4.1 FN Curve

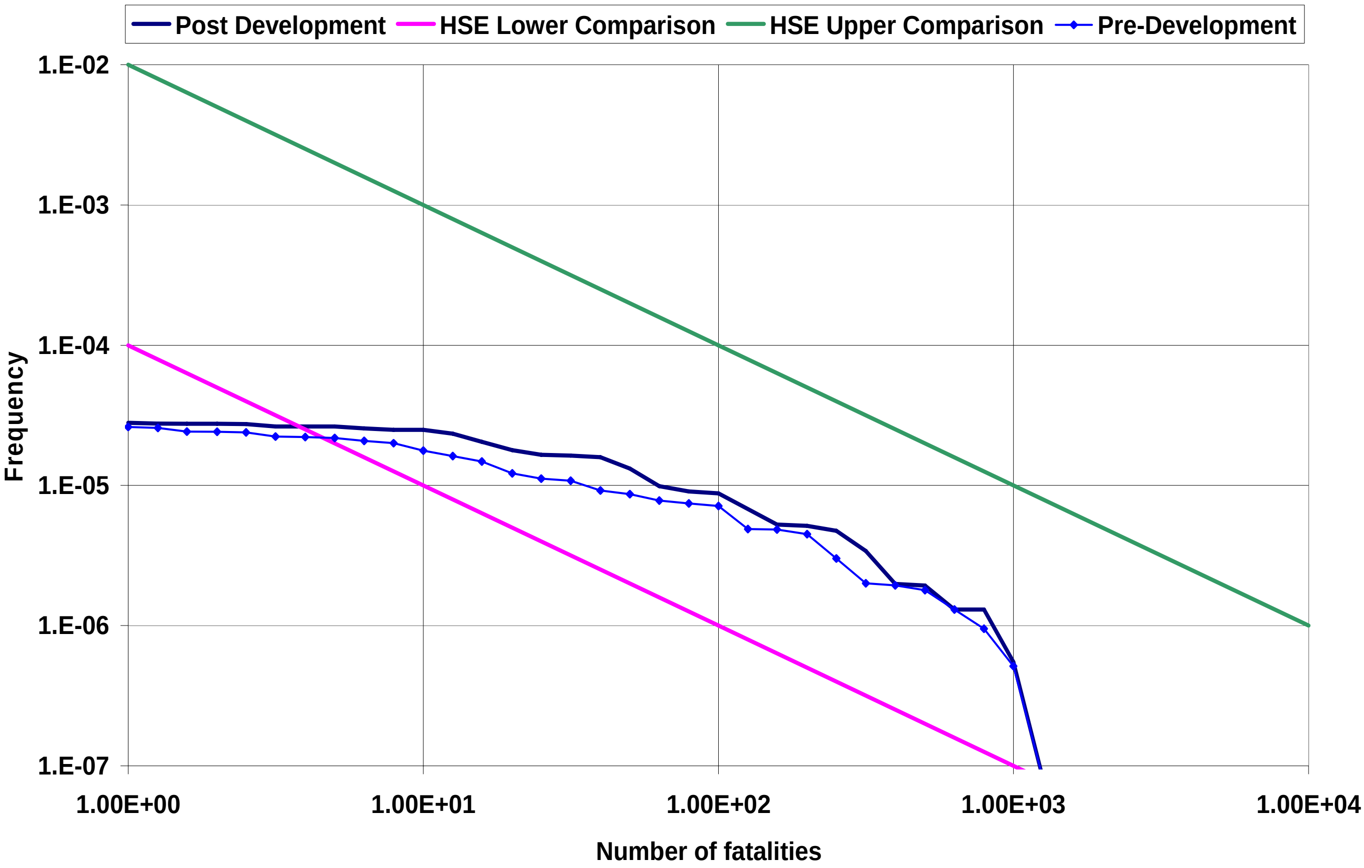
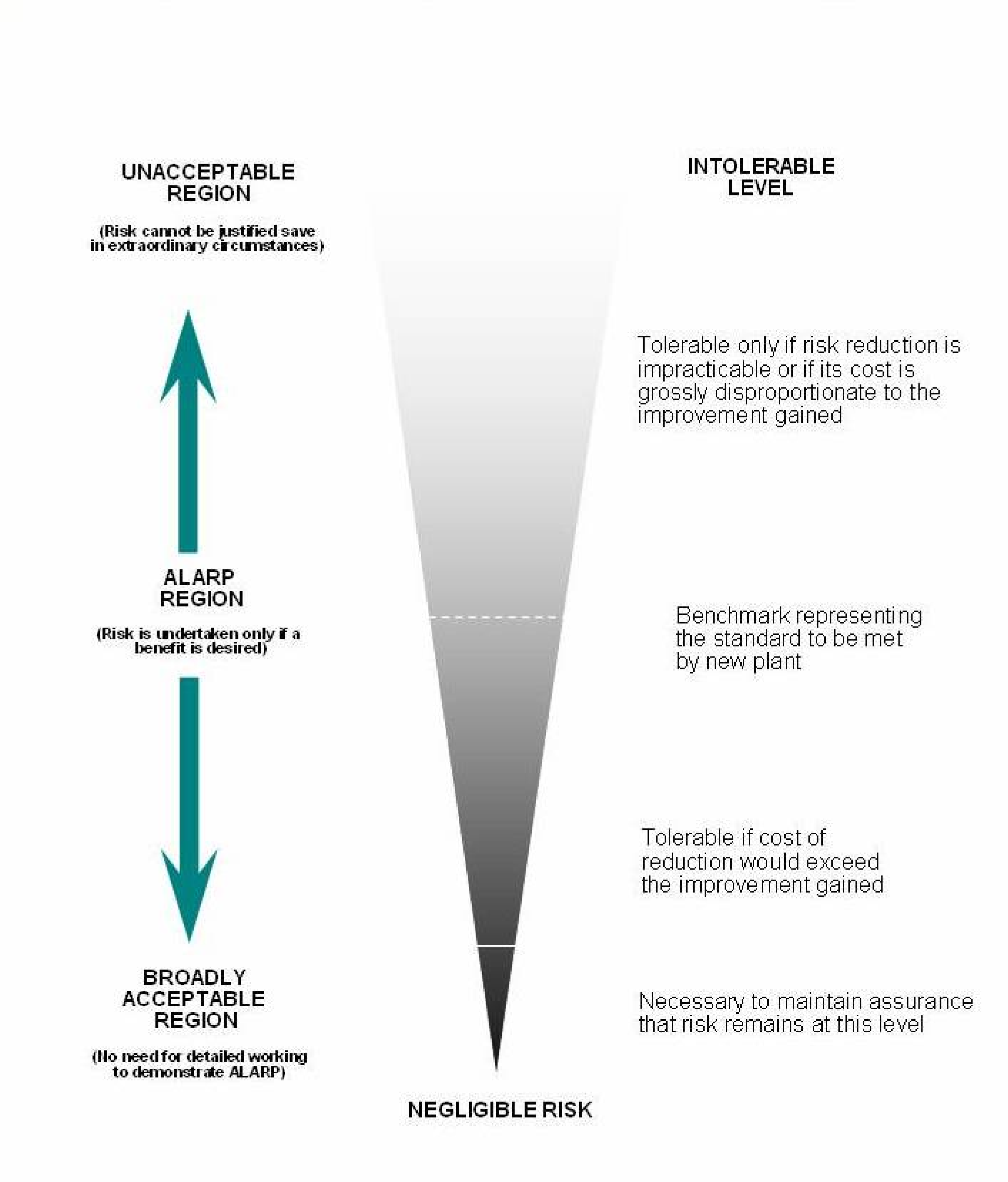


Figure 5.1 HSE Framework for tolerability of risk



APPENDIX A

Population Data

A1 INTRODUCTION

This appendix includes data for the following 3 categories of population:

1 Residential

This information is drawn from the 2001 census output, and is given in Table A.1 against the output areas identified in Figure A1. It is estimated that there is a total residential population of around 12,600 within 500m of the gas holder site.

2 Employee

This information is provided against regions which cover several census output areas. The key, to be compared with Figure A1, is given in Table A2, and the employee numbers are given in Table A3.

3 Sensitive populations

Schools and other facilities at which sensitive populations may be present are shown in Figure A2. The approximate population data for the schools identified within the zones are:

Mowlem Primary School	260
Oaklands Secondary School	650
Raines Annexe Secondary School	550
Beatrice Tate Secondary School	90
St Johns Primary School	260
Lawdale Primary School	335
London Fields Primary School	490
Sebright primary School	460

St Joseph's Hospice has an approximate population of 100-120 persons.

The numbers that attend the adult day centres identified appear to be quite low.

Table A1 Residential Population Data

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Borough	Output Area Code	Population within 500m	Total Population	Area within 500m buffer (m2)	Total area (m2)	Fraction within 500m	Weighted population based on area fraction
Tower Hamlets	00BGFW0001	341	341	20037.48	20037.48	1.00	341
Tower Hamlets	00BGFW0002	253	253	82016.10	82016.10	1.00	253
Tower Hamlets	00BGFW0004	252	252	73362.21	73362.26	1.00	252
Tower Hamlets	00BGFW0005	15	245	1076.96	18058.40	0.06	15
Tower Hamlets	00BGFW0006	416	416	14003.02	14003.02	1.00	416
Tower Hamlets	00BGFW0008	196	238	20697.70	25112.64	0.82	196
Tower Hamlets	00BGFW0009	307	307	11116.43	11116.43	1.00	307
Tower Hamlets	00BGFW0010	40	275	1709.77	11882.46	0.14	40
Tower Hamlets	00BGFW0011	303	303	9595.21	9595.21	1.00	303
Tower Hamlets	00BGFW0012	418	418	17555.69	17555.69	1.00	418
Tower Hamlets	00BGFW0013	232	232	12926.50	12926.50	1.00	232
Tower Hamlets	00BGFW0014	414	414	17591.35	17591.35	1.00	414
Tower Hamlets	00BGFW0015	204	204	12799.39	12799.39	1.00	204
Tower Hamlets	00BGFW0016	208	209	23191.21	23267.01	1.00	208
Tower Hamlets	00BGFW0017	330	330	11122.02	11122.02	1.00	330
Tower Hamlets	00BGFW0018	338	338	9994.88	9994.88	1.00	338
Tower Hamlets	00BGFW0019	450	533	24330.55	28788.56	0.85	450
Tower Hamlets	00BGFW0020	194	284	13359.03	19537.74	0.68	194
Tower Hamlets	00BGFW0021	214	320	15074.07	22554.94	0.67	214
Tower Hamlets	00BGFW0022	177	410	6346.00	14669.47	0.43	177
Tower Hamlets	00BGFW0023	64	335	6674.34	35024.60	0.19	64
Tower Hamlets	00BGFW0025	191	276	18822.71	27186.14	0.69	191
Tower Hamlets	00BGFW0026	1	387	28.06	11903.22	0.00	1
Tower Hamlets	00BGFW0028	17	266	1922.80	29794.52	0.06	17
Tower Hamlets	00BGFW0029	445	445	18507.56	18507.58	1.00	445
Tower Hamlets	00BGFW0030	453	453	14194.16	14208.22	1.00	453
Tower Hamlets	00BGFW0031	325	325	39812.43	39812.43	1.00	325
Tower Hamlets	00BGFW0032	46	294	4469.37	28261.16	0.16	46
Tower Hamlets	00BGFW0034	197	197	7785.77	7785.77	1.00	197
Tower Hamlets	00BGFW0035	5	319	772.10	48777.36	0.02	5
Tower Hamlets	00BGFW0036	208	310	10607.66	15831.83	0.67	208
Tower Hamlets	00BGFW0037	462	462	12527.16	12527.16	1.00	462
Tower Hamlets	00BGGA0002	1	347	649.56	443184.41	0.00	1
Tower Hamlets	00BGGE0020	0	249	93.46	47586.03	0.00	0
Tower Hamlets	00BGGM0004	66	300	7674.85	34794.37	0.22	66
Tower Hamlets	00BGGM0028	100	276	4942.32	13701.20	0.36	100
Tower Hamlets	00BGGM0029	7	277	454.63	17076.71	0.03	7
Tower Hamlets	00BGGM0031	9	240	560.93	14723.72	0.04	9
Hackney	00AMGJ0001	196	196	37985.69	37985.74	1.00	196
Hackney	00AMGJ0013	328	328	18083.04	18083.04	1.00	328
Hackney	00AMGJ0014	223	295	34406.25	45443.76	0.76	223
Hackney	00AMGJ0017	310	310	13549.28	13549.28	1.00	310
Hackney	00AMGJ0021	324	324	11778.94	11778.95	1.00	324
Hackney	00AMGJ0025	87	233	30779.62	82040.89	0.38	87
Hackney	00AMGQ0002	221	272	17301.82	21330.96	0.81	221
Hackney	00AMGQ0021	18	264	7204.13	103243.07	0.07	18
Hackney	00AMGQ0025	105	235	13407.66	29922.58	0.45	105
Hackney	00AMGQ0027	98	376	9283.32	35572.78	0.26	98
Hackney	00AMGQ0029	323	323	21543.58	21543.58	1.00	323
Hackney	00AMGQ0030	265	265	14864.65	14864.65	1.00	265
Hackney	00AMGQ0032	222	227	48264.05	49264.94	0.98	222
Hackney	00AMGQ0033	423	423	16906.44	16906.44	1.00	423
Hackney	00AMGQ0034	258	360	11136.81	15557.36	0.72	258
Hackney	00AMGQ0036	279	279	77743.04	77743.06	1.00	279
Hackney	00AMGT0005	28	333	2012.30	23914.24	0.08	28
Hackney	00AMGT0009	222	398	18548.33	33208.00	0.56	222
Hackney	00AMGT0024	241	250	20212.68	20955.43	0.96	241
Hackney	00AMGT0026	53	326	1793.90	10948.41	0.16	53
Hackney	00AMGT0030	164	306	13217.58	24705.32	0.54	164
Hackney	00AMGT0031	282	282	16134.80	16134.80	1.00	282

Figure A1 Census Output Areas

Table A2 Key to Employee Data Areas

Output Area Code	Lower Super Output Area Code	Middle Super Output Area Code	Middle Super Output Area Name	Ward Name	Local Authority
00AMGQ0015	E01001818	E02000367	Hackney 023	Queensbridge	Hackney
00AMGQ0021	E01001818	E02000367	Hackney 023	Queensbridge	Hackney
00AMGQ0025	E01001818	E02000367	Hackney 023	Queensbridge	Hackney
00AMGQ0029	E01001818	E02000367	Hackney 023	Queensbridge	Hackney
00AMGQ0032	E01001818	E02000367	Hackney 023	Queensbridge	Hackney
00AMGQ0036	E01001818	E02000367	Hackney 023	Queensbridge	Hackney
00AMGT0009	E01001837	E02000367	Hackney 023	Victoria	Hackney
00AMGT0024	E01001837	E02000367	Hackney 023	Victoria	Hackney
00AMGT0025	E01001837	E02000367	Hackney 023	Victoria	Hackney
00AMGT0030	E01001837	E02000367	Hackney 023	Victoria	Hackney
00AMGT0031	E01001837	E02000367	Hackney 023	Victoria	Hackney
00AMGT0005	E01001842	E02000367	Hackney 023	Victoria	Hackney
00AMGT0014	E01001842	E02000367	Hackney 023	Victoria	Hackney
00AMGT0020	E01001842	E02000367	Hackney 023	Victoria	Hackney
00AMGT0023	E01001842	E02000367	Hackney 023	Victoria	Hackney
00AMGT0026	E01001842	E02000367	Hackney 023	Victoria	Hackney
00AMGJ0018	E01001774	E02000368	Hackney 024	Haggerston	Hackney
00AMGJ0023	E01001774	E02000368	Hackney 024	Haggerston	Hackney
00AMGJ0024	E01001774	E02000368	Hackney 024	Haggerston	Hackney
00AMGJ0025	E01001774	E02000368	Hackney 024	Haggerston	Hackney
00AMGJ0033	E01001774	E02000368	Hackney 024	Haggerston	Hackney
00AMGJ0001	E01001775	E02000368	Hackney 024	Haggerston	Hackney
00AMGJ0013	E01001775	E02000368	Hackney 024	Haggerston	Hackney
00AMGJ0014	E01001775	E02000368	Hackney 024	Haggerston	Hackney
00AMGJ0017	E01001775	E02000368	Hackney 024	Haggerston	Hackney
00AMGJ0021	E01001775	E02000368	Hackney 024	Haggerston	Hackney
00AMGQ0008	E01001815	E02000368	Hackney 024	Queensbridge	Hackney
00AMGQ0016	E01001815	E02000368	Hackney 024	Queensbridge	Hackney
00AMGQ0022	E01001815	E02000368	Hackney 024	Queensbridge	Hackney
00AMGQ0024	E01001815	E02000368	Hackney 024	Queensbridge	Hackney
00AMGQ0027	E01001815	E02000368	Hackney 024	Queensbridge	Hackney
00AMGQ0002	E01001821	E02000368	Hackney 024	Queensbridge	Hackney
00AMGQ0030	E01001821	E02000368	Hackney 024	Queensbridge	Hackney
00AMGQ0033	E01001821	E02000368	Hackney 024	Queensbridge	Hackney
00AMGQ0034	E01001821	E02000368	Hackney 024	Queensbridge	Hackney
00BGFW0002	E01004197	E02000865	Tower Hamlets 002	Bethnal Green North	Tower Hamlets
00BGFW0005	E01004197	E02000865	Tower Hamlets 002	Bethnal Green North	Tower Hamlets
00BGFW0030	E01004197	E02000865	Tower Hamlets 002	Bethnal Green North	Tower Hamlets
00BGFW0031	E01004197	E02000865	Tower Hamlets 002	Bethnal Green North	Tower Hamlets
00BGFW0036	E01004197	E02000865	Tower Hamlets 002	Bethnal Green North	Tower Hamlets
00BGFW0001	E01004198	E02000865	Tower Hamlets 002	Bethnal Green North	Tower Hamlets
00BGFW0008	E01004198	E02000865	Tower Hamlets 002	Bethnal Green North	Tower Hamlets
00BGFW0010	E01004198	E02000865	Tower Hamlets 002	Bethnal Green North	Tower Hamlets
00BGFW0016	E01004198	E02000865	Tower Hamlets 002	Bethnal Green North	Tower Hamlets
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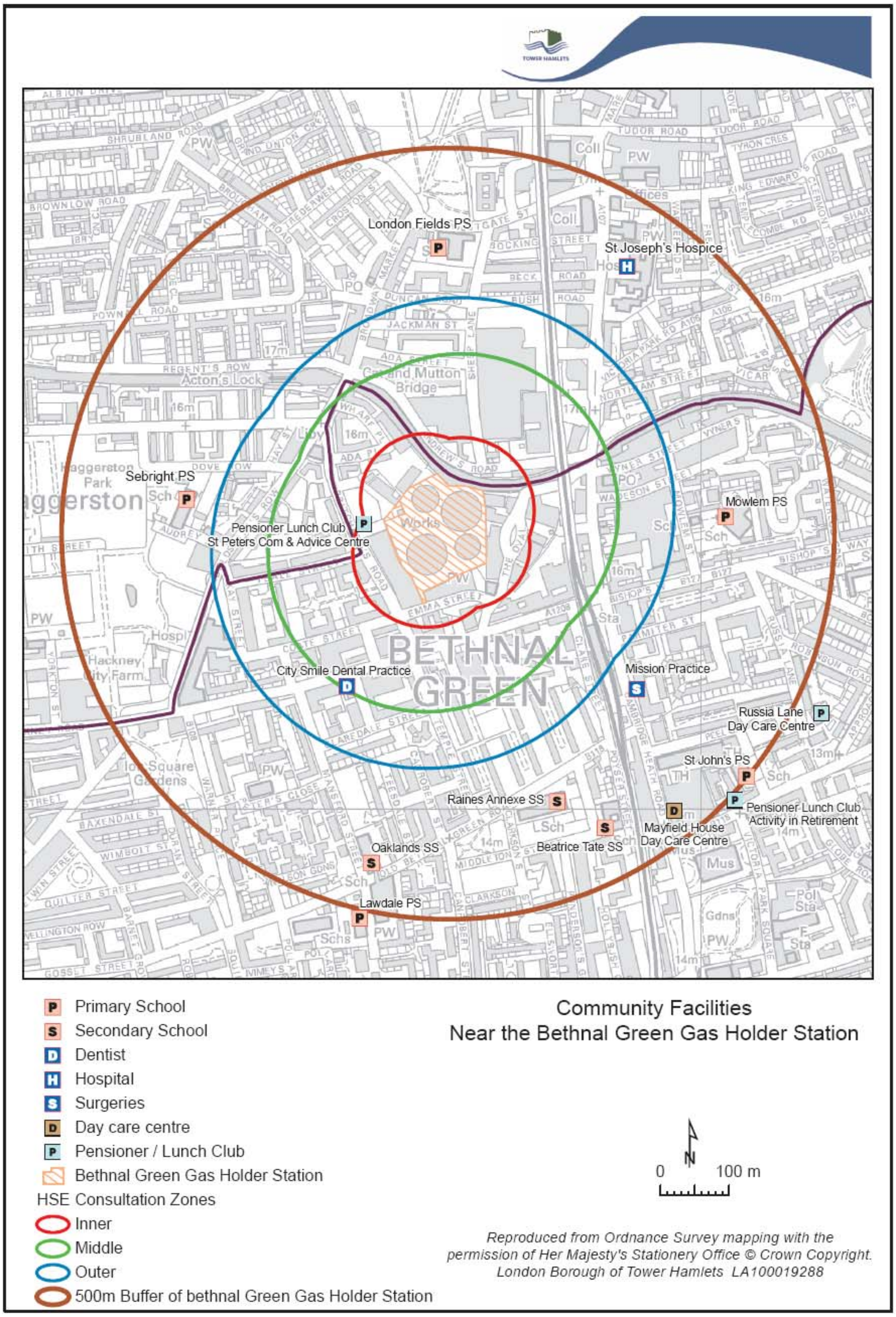
00BGFW0032	E01004201	E02000865	Tower Hamlets 002	Bethnal Green North	Tower Hamlets
00BGFW0033	E01004201	E02000865	Tower Hamlets 002	Bethnal Green North	Tower Hamlets
00BGFW0035	E01004201	E02000865	Tower Hamlets 002	Bethnal Green North	Tower Hamlets
00BGGA0002	E01004234	E02000866	Tower Hamlets 003	Bow West	Tower Hamlets
00BGGA0003	E01004234	E02000866	Tower Hamlets 003	Bow West	Tower Hamlets
00BGGA0019	E01004234	E02000866	Tower Hamlets 003	Bow West	Tower Hamlets
00BGGA0020	E01004234	E02000866	Tower Hamlets 003	Bow West	Tower Hamlets
00BGGA0021	E01004234	E02000866	Tower Hamlets 003	Bow West	Tower Hamlets
00BGGA0024	E01004234	E02000866	Tower Hamlets 003	Bow West	Tower Hamlets
00BGFW0006	E01004200	E02000868	Tower Hamlets 005	Bethnal Green North	Tower Hamlets
00BGFW0013	E01004200	E02000868	Tower Hamlets 005	Bethnal Green North	Tower Hamlets
00BGFW0014	E01004200	E02000868	Tower Hamlets 005	Bethnal Green North	Tower Hamlets
00BGFW0015	E01004200	E02000868	Tower Hamlets 005	Bethnal Green North	Tower Hamlets
00BGFW0004	E01004202	E02000868	Tower Hamlets 005	Bethnal Green North	Tower Hamlets
00BGFW0029	E01004202	E02000868	Tower Hamlets 005	Bethnal Green North	Tower Hamlets
00BGFW0034	E01004202	E02000868	Tower Hamlets 005	Bethnal Green North	Tower Hamlets
00BGFW0037	E01004202	E02000868	Tower Hamlets 005	Bethnal Green North	Tower Hamlets
00BGFW0020	E01004203	E02000868	Tower Hamlets 005	Bethnal Green North	Tower Hamlets
00BGFW0021	E01004203	E02000868	Tower Hamlets 005	Bethnal Green North	Tower Hamlets
00BGFW0026	E01004203	E02000868	Tower Hamlets 005	Bethnal Green North	Tower Hamlets

Table A3 Employee Data

LSOA_CODE	500m Radius Area	SOA_Area	Proportional_Area	TOTAL	Emp_Ratio
E01001774	30779.65	179566.03	0.17	843	143.31
E01001775	115803.09	126840.61	0.91	108	98.28
E01001815	9283.19	108964.77	0.09	57	5.13
E01001818	168162.46	381334.22	0.44	2176	957.44
E01001821	60209.99	68659.75	0.88	58	51.04
E01001837	68114.08	111400.39	0.61	395	240.95
E01001842	3806.04	64684.66	0.06	67	4.02
E01004197	147707.28	169927.33	0.87	1074	934.38
E01004198	71981.77	94968.93	0.76	557	423.32
E01004199	60650.32	69013.60	0.88	68	59.84
E01004200	57320.64	57320.64	1.00	159	159.00
E01004201	5241.46	129814.16	0.04	644	25.76
E01004202	112182.91	112182.91	1.00	527	527.00
E01004203	30384.15	105158.20	0.29	954	276.66
E01004204	48560.82	84457.98	0.57	421	239.97
E01004234	649.69	573205.32	0.00	250	0.00
E01004259	93.47	133233.23	0.00	1792	0.00
E01004314	8235.71	83243.71	0.10	260	26.00
E01004318	5397.00	58667.01	0.09	229	20.61

Figure A2 Locations of Sensitive Populations



APPENDIX B

Excerpt from PADHI Sensitivity Table

Development type	Examples	Development detail and size	Justification
DT2.1 - Housing	Houses, flats, retirement flats/ bungalows, residential caravans, mobile homes.	Developments up to and including 30 dwelling units **and** at a density of no more than 40 per hectare – **Level 2**	Development where people live or are temporarily resident. It may be difficult to organise people in the event of an emergency.
EXCLUSIONS			
Infill, backland development.	**DT2.1 x1** Developments of 1 or 2 dwelling units - **Level 1**	Minimal increase in numbers at risk.	
Larger housing developments.	**DT2.1 x2** Larger developments for more than 30 dwelling units – **Level 3**	Substantial increase in numbers at risk.	
	DT2.1 x3 Any developments (for more than 2 dwelling units) at a density of more than 40 dwelling units per hectare - **Level 3**	High-density developments.	
DT2.2 - Hotel/Hostel/ Holiday Accommodation	Hotels, motels, guest houses, hostels, youth hostels, holiday camps, holiday homes, halls of residence, dormitories, accommodation centres, holiday caravan sites, camping sites.	Accommodation up to 100 beds or 33 caravan / tent pitches – **Level 2**	Development where people are temporarily resident. It may be difficult to organise people in the event of an emergency.
EXCLUSIONS			
Smaller - guest houses, hostels, youth hostels, holiday homes, halls of residence, dormitories, holiday caravan sites, camping sites.	**DT2.2 x1** Accommodation of less than 10 beds or 3 caravan / tent pitches - **Level 1**	Minimal increase in numbers at risk.	
Larger – hotels, motels, hostels, youth hostels, holiday camps, holiday homes, halls of residence, dormitories, holiday caravan sites,	**DT2.2 x2** Accommodation of more than 100 beds or 33 caravan / tent pitches–	Substantial increase in numbers at risk.	

camping sites.	**Level 3**		
DT2.3 - Transport Links	Motorway, dual carriageway.	Major transport links in their own right; i.e. not as an integral part of other developments – **Level 2**	Prime purpose is as a transport link. Potentially large numbers exposed to risk, but exposure of an individual is only for a short period.
EXCLUSIONS			
Estate roads, access roads.	**DT2.3 x1** Single carriageway roads – **Level 1**	Minimal numbers present and mostly a small period of time exposed to risk. Associated with other development.	

APPENDIX C

Assessment of Accident Statistics for Water Sealed Gas Holders

C1 DATA AND ASSUMPTIONS

The following data were available for the study:

1) Information on major accidents occurring between 1912 and 1930 and causing total decoupling of seals, with or without gas ignition and total collapse of the gas holder (Ref. 1).
2) Database of accidents involving gas leaks, with or without ignition, between 1970 and 2000 (Appendix 1 of Ref. 1). These are derived from Transco records. It is important to note that some information related to the above holder accidents has not been disclosed by HSE. In addition, because stations are generally un-staffed, Reference 1 presumes that reliance is made by Transco on reports from the public and analyses of post-accident damage for an estimate of mass of release and causes. Furthermore, it is noted that some inconsistencies in the dataset were observed; these are described in Section C2.
3) Information on the gas holder population and industry development from 1910 (Ref. 1).

In order to use the available information for the derivation of statistical accident frequencies, the following assumptions and refinements on the above data were made. Figures for the number of gas holders active in the United Kingdom over the years, from 1970 were derived from 3). In particular, Reference 1 reports that until the end of the 60s the estimate of water-sealed gasholders in operation in the UK was between 5000 and 6000; hence a constant population of 5500 gasholders was assumed for those years. Information on the subsequent decreases in the number of gas holders in use is given in Reference 1. It is reported that between 1970 and 1980 the gasholder population diminished from 5500 to 1000, between 1980 and 1995 from 1000 to 500 and between 1995 and 2002 from 500 to 400.

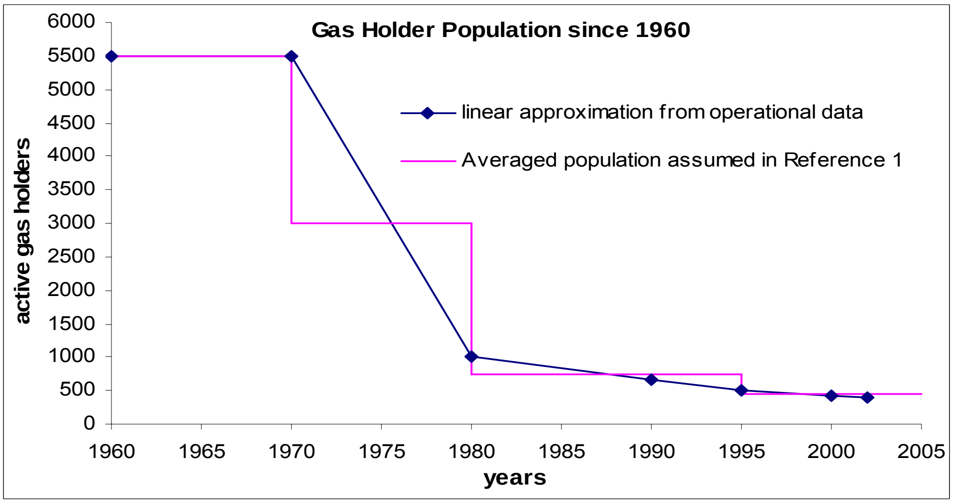


Figure C1 Reduction of gas holder population over time since 1960

From these figures the approximate numbers for the population of gas holders active each year between 1910 and 2002 could be obtained, assuming linear reductions of active gas holder numbers, as shown in Figure C1. The diagram depicts the linear approximations derived for the present analysis and the average values used in Reference 1 for comparison.

C2 EVENT FREQUENCY ANALYSIS

C2.1 Analysis of Large Historical Events

Only 6 major accidents have been reported where decoupling and / or collapse of gas holders have occurred. Three of these, i.e. 50% of the incidents, involved the ignition of the gas which had escaped and two resulted in a total collapse of the holders; all of them happened between 1910 and 1930. Reference 1 derives frequencies for major accidents by dividing the number of accidents by the total number of gas holder operational years (3.76 x 10^5), treating these as a single dataset. In this analysis, data have been treated statistically slightly differently and the specific holder population in operation during the decade when the accident(s) occurred was applied to derive a ten-year frequency and the frequencies obtained during all decades (non-null only for the first two decades) were averaged over the entire period covered. The results are reported in Table C1.

Years		**Events**			**Frequency (events / holder / yr)**		
Period	Holder years	Total collapse	De-coupled seals with ignition	De-coupled seals all	Total collapse	De-coupled seals with ignition	De-coupled seals all
1910 - 1920	55000	1	1	3	1.82×10^{-5}	1.82×10^{-5}	5.45×10^{-5}
1920 - 1930	55000	1	2	3	1.82×10^{-5}	3.64×10^{-5}	5.45×10^{-5}
1930 - 1940	55000	0	0	0	0	0	0
1940 - 1950	55000	0	0	0	0	0	0
1950 - 1960	55000	0	0	0	0	0	0
1960 - 1970	55000	0	0	0	0	0	0
1970 - 1980	32500	0	0	0	0	0	0
1980 - 1990	8330	0	0	0	0	0	0
1990 - 2000	5480	0	0	0	0	0	0
2000 - 2005	2030	0	0	0	0	0	0
Average					3.83×10^{-6}	5.74×10^{-6}	1.15×10^{-5}

Table C1 Frequencies of accidents involving total collapse and seal de-couplement, averaged over periods of 10 years.

Table C2 compares the average probabilities obtained as described above with those reported in Reference 1. It can be seen that the estimates calculated through this study are to be slightly lower than those reported in Reference 1.

Accidents involving total collapse and seal de-couplement	Frequency (cpm / holder / year)	
	Calculated	From Reference 1
All	11.5	~15
Decoupled seal (or worse) with ignition	5.7	~10
Total collapse with ignition	3.8	~5

Table C2 Comparison between calculated frequencies of accidents involving total collapse and seal de-couplement and corresponding figures obtained in Reference1.

C2.2 ALTERNATIVE ESTIMATION

Because the only major accidents recorded in the industry have occurred several decades ago and no other accidents have been reported since, Reference 2 derives an estimate of expected frequency, excluding the past events, through the application of the Poisson distribution model.

If:

x is the level of confidence of the estimate in percentage

n is the period (in holder years) without accidents

then the expected frequency F_x can be calculated by applying the following formula:

$$F_x = \frac{-\ln(1 - x/100)}{n}$$

Taking a 90% confidence interval and considering an approximate number of gasholder years of 1 x 10^5 since nationalisation, Reference 2 estimates a frequency F_{90} of 2.1 x 10^{-5} events per holder per year. Furthermore, a 50% ignition probability for major accidents is assumed, which leads to a prediction of about 10 x 10^{-6} ignited decoupled seal accidents / holder / year with a 90% confidence. Of these, 10% are assumed to be as a result of total collapse, with a resulting estimated frequency of 1 x 10^{-6}.

However, the total number of holder years derived in Reference 1 over the accident free period (since 1930) and since nationalisation (1950) is respectively 2.5 x 10^5 and 1.5 x 10^5. If these values are used in the application of the Poisson formula, for a 90% confidence interval, the following estimates are obtained:

Since 1930 $$F_{90} = \frac{-\ln(1 - 90/100)}{2.5 \times 10^5} = 9.2 \times 10^{-6}$$ events/holder/year

Since 1950 $$F_{90} = \frac{-\ln(1 - 90/100)}{1.5 \times 10^5} = 1.5 \times 10^{-5}$$ events/holder/year

The table below compares these figures to those obtained in Reference 2 together with frequencies for ignited decoupled seal accidents and total collapse accidents derived by applying the same factors assumed in Reference 2.

Accidents involving total collapse and decoupled seal (or worse) with ignition	Frequency (cpm / holder / year)		
	From Reference 1	Calculated since 1950	Calculated since 1930
All	21	15	~9
Decoupled seal (or worse) with ignition	10	~7.5	~4.5
Total collapse with ignition	~1	~0.75	~0.45

Table C3 Comparison between predicted frequencies for accidents involving total collapse and decoupled seal (or worse) assuming a 50% probability of ignition.

C3 ANALYSIS OF RECENT INCIDENT DATA

C3.1 BACKGROUND

A review has been carried out for gas holder incidents occurring between 1970 and 2000, details of which are provided in Appendix 1 of Reference 1. One hundred and twenty nine events are reported to have occurred during the period and involved gas leaks of various magnitudes from water-sealed gas holders. Because the data reported were obtained only through partial disclosure of information and through public report and post-accident analysis, they often lack details in terms of quantities released and accident causes. In particular, for approximately 55% of the cases, the gas leak has not been quantified.

In reviewing the dataset, it was also noted that for two pairs of entries reported separately in the dataset the details given appear remarkably similar, suggesting that each pair actually refers to the same event. For the purpose of this review, each pair will be considered as representative of a single incident. (It is noted that the events in the dataset of Reference 1 are reported in chronological order, with the exception of the two spurious duplicate entries, which, therefore, appear to be recorded erroneously). The total number of events used in the present analysis from Reference 1 is therefore 127. Although 'major releases' have been recorded in several instances, it is not suggested that any of these accidents have produced a full seal de-couplement or holder collapse.

Figure C2 shows the event distribution between 1970 and 2000. Over the period covered, with the exception of isolated peaks, the accident trend shows a fairly random and reasonably uniform spread with an average of 4-5 accidents per year. However, if the number of events per year is normalised with respect to the actual holder number in operation during the year, the resulting frequency appears to be increasing steadily (with the sporadic superimposed peaks), as shown in Figure C3. This might be attributable to the fact that, whilst the population of holders has decreased significantly over the last 30 years, it is likely that the holders being decommissioned are actually those that in recent years have not been in operation (full utilisation). Whereas before decommissioning these holders might have been considered as part of the total populations, they would not have been equally susceptible to accidents (hence the apparent lower accident probability). The resulting total average probability is 5.4×10^{-3}. This is calculated as the average of the annual frequency obtained by dividing the number of events per year by the gas holder population in the same year and averaging the annual frequencies obtained over the three decades 1970 -2000. If the gasholder operational years were treated as a single dataset, the total frequency would be obtained by dividing the number of events (127) by the integrated gas holder population over the 30 years of operation considered (48950), giving rise to more optimistic predictions (2.6×10^{-3}).

Of the accidents recorded, 13% are reported in Appendix 1 of Reference 1 to have caused releases greater than 30te (major releases), all attributable to seal failure, except one case of overfilling. The resulting yearly probability for major releases is, therefore, $5.4 \times 10^{-3} \times 0.13 = 7.1 \times 10^{-4}$ per holder per year.

It is interesting to note that in only four instances did the accidental gas leaks ignite, and none of these cases were explicitly related to major releases (Ref.1). In three cases ignition was attributed to faulty electrical antifreeze equipment and in one instance to spark generated from a hand grinder. None of the events occurred after 1985. Ignited leaks therefore represent approximately only 3% of the totality of accidents which occurred in the period under review, with a resulting probability of $5.4 \times 10^{-3} \times 0.03 \approx 1.7 \times 10^{-4}$.

C3.2 Cause Analysis

A review of potential causes was undertaken for the set of events reported in Appendix 1 of Reference 1 for the period 1970 – 2000. Gas holder accidents were grouped under the categories indicated in Table C4, and a pie chart of the causal distribution given above is given in Figure C4.

Cause	Number of events	Percentage
Corrosion in water seal	24	19%
High winds	9	7%
Snow load	3	2%
Overfilling	13	10%
Low temperatures	1	1%
Evaporation	3	2%
Equipment / Mechanical Failure	34	27%
Human error	6	5%
Ignited seal	4	3%
N/R / other / unknown	30	24%

Table C4 Causal distribution of gas holder accidents for the period 1970 – 2000.

For a large percentage of accidents (24%), the cause was not reported or was reported as unknown. For the remaining cases, the two predominant accident roots are mechanical / equipment failures (38%), with a distinct high contribution of water seals failing due to corrosion (19%) and a substantial single contribution from failure of the antifreeze system. It is interesting to note that, out of the four instances resulting in fire, in three cases ignition was attributed to faulty electrical antifreeze equipment. The next most significant source of releases is overfilling (due to mechanical problems or human error).

Factors such as low temperatures, snow load and evaporation, identified in Reference 1 as potential causes for major accidents (de-couplement and holder collapse), have been recognised as the possible origin of a small number of releases (1 instance due to low temperatures, 3 due to snow load and 3 due to evaporation over 30 years). However, in none of these events were large releases reported and the overall contribution, compared to the total number of accidents, is of little significance. On the other hand, in Reference 1, a greater number of events (9) are attributed to (or were recorded as occurring in the presence of) high winds, also recognised as a potential cause for major accidents.

The following initiators are of particular interest for gas holder safety assessments and hence have been considered separately:

- Split crown
- Overfilling
- Seal failure

Table C5 below summarises statistical data and frequencies related to the three initiators. Frequencies have been calculated as fractions of the total average frequency derived above (5.4×10^{-3}).

Initiator	Number of events	Percentage over total number of events	Frequency
Split crown	7	5.5%	3.0×10^{-4}
Overfilling	13	10.2%	5.6×10^{-4}
Seal Failure	33	25.9%	1.4×10^{-3}

Table C5 Statistical data and frequencies related to accident caused by: split crown, overfilling, and seal failure.

Whereas release quantities were not specified for any of the split crown events, a number of overfilling and seal failure accidents were reported to have resulted in leaks of different severity, including major releases.

C3.3 Release Size Assessment

A classification of accidental releases from gas holders reported in Reference 1 for the period 1970 – 2000 was carried out on the basis of the mass of gas. When considering the quantification of releases, there is an even greater percentage of cases (55%) for which the amounts of gas released are not specified. If the same severity distribution from quantified releases (45% of events) is applied to the 55% un-quantified events, reasonably conservative release percentages can be estimated. Actual and projected figures are summarised in Table C6 below, and the release distributions given in the table are represented in Figures C5 and C6 through pie charts.

Quantity of gas released [te]	Number of actual events	Percentage	
		Reported	Projected
0 – 10	30	24%	53%
10 – 20	8	6%	14%
20 – 30	3	2%	5%
30 – 40	4	3%	7%
40 – 50	11	9%	19%
> 50	1	1%	2%
NR	70	55%	

Table C6 Release distribution of gas holder accidents for the period 1970 – 2000.

The majority of recorded releases (24% reported, 53% projected) were relatively small. A small number of reported accidents (11) gave rise to gas leaks between 40te and 50te. These were all attributable to mechanical / equipment failure, including corrosion in the water seal. In total, 16 'major releases' which gave rise to discharges greater than 30te are reported in Reference 1, i.e. 13% of the total number of accidents considered. However, if same the severity distribution from quantified releases is also applied to un-quantified events, a considerably greater contribution of major release would be obtained, corresponding to an estimated percentage of 28%. It is evident how crucial would be the knowledge of the effective distribution of events for which information is undisclosed or partial.

C4 DISCUSSION

The causal distribution of accidental leaks recorded for the period 1970 – 2000 was derived, as reported in Section C.3.2. The analysis showed that the predominant causes for gas holder accidents are mechanical / equipment failures including corrosion of seals, followed by overfilling. Extreme weather conditions (snow loading, extreme temperatures and high winds) have been identified in Reference 1 as potential causes of de-couplement or total collapse of gas holders. However the recorded experience shows that only in very sporadic instances did snow loading and extreme temperatures result in minor releases (3 and 1 incidents respectively). A greater number of incidences (9) were attributed to high winds.

It is interesting to note that only 4 cases of ignited leaks were recorded, over 127 accidents. None of the accidents recorded to have caused major releases ignited. Recent historical data demonstrate that the percentage of all accidents escalating in the ignition of leaks is very small – 3%. It may be argued that, in past years (e.g. 1920s – 30s), the ignition sources in the vicinity of gas holder installations would be many more. On the other hand, however, electrical antifreeze equipment, which appears to have been the cause for three out of four ignited releases and a number of further non-ignited leaks, was not used at the time. For ignited releases from total collapse / de-couplement accidents, the mechanisms of ignition could be different. Sources such as metal / metal sparking during collapse could be intrinsic to the accident modality and very local to the leak, causing ignition to be nearly instantaneous and more probable.

Release distributions were also derived for the same set of recent accidents. The majority of recorded releases (23%) were smaller than 10te. Only a small number of accidents (12), all due to mechanical / equipment failures, gave rise to gas leaks greater than 40te. These represent 10% of the reported events. However, if the severity distribution from quantified releases (45% of events) is applied to the 55% un-quantified events, the percentage of releases greater than 40te would go up to 21%.

C5 CONSIDERATION OF IGNITION PROBABILITY

Since the molecular weight of methane is 16, its density is only 55% of that of air, ie. 0.678kg/m^3, and any release of natural gas will experience a significant buoyancy force. This will lift it up, and hence away from the ground where most likely ignition sources will be present. The effects of this buoyancy can be approximately assessed by assuming that any large volume of gas which is released will form a sphere, which will accelerate until it rises through the air with a terminal velocity.

Mass released = M kg

Volume release = $\frac{M}{0.678}$ m^3

Radius of Sphere = $\left(\frac{3}{4\pi} x \frac{M}{0.678}\right)^{1/3} = 0.71M^{1/3}$ (m)

Downward force on sphere = Mg

Upward buoyancy force = $\frac{M}{0.678} x1.225g$

Hence, net upward force = $Mg\left(\frac{1.225 - 0.678}{0.678}\right)$

= 0.81Mg

If this bubble moves upwards at v m/s, the drag force = $\frac{1}{2}\rho AV^2 C_D$, where

ρ = density of air

C_D = drag coefficient (=2 for a sphere)

A = cross sectional area of bubble

= πr^2 = 1.58 $M^{2/3}$

The terminal velocity is attained when the net upward force is equal to the drag force: 0.81Mg = $\frac{1}{2} x1.225x1.58M^{2/3} xV^2 x2$

ie. $V^2 = \frac{0.81gM^{1/3}}{1.225x1.58} = 4.08M^{1/3}$

Hence $V = 2.02M^{1/6}$

For M=78,000kg (78t), this gives a terminal velocity of around 13m/s. It can be shown that 95% of this velocity is attained within the first 3 seconds, at which time the gas ‘bubble’ will have risen around 24m. Clearly, the gas will begin to disperse, forming a slightly less buoyant but larger cloud, for which the buoyancy force will be reduced, and the radius (and therefore the drag force) increased. However, the release mechanism is such that there is unlikely to be rapid initial mixing, which implies that the other calculations given above will apply to first order.

Although the HSE assessment of the 6 major releases in the early 20th century implied an ignition probability of 50%, this is considered to be overly conservative for the following reasons:

a.) The greater ignitability of town gas (predominantly hydrogen) than that of the currently used natural gas (predominantly methane).

b.) The potential under-reporting of large unignited releases. (It is unlikely that large ignited releases would go unreported.)

c.) The size of the buoyancy effects noted above.

d.) The historical record for 1970-2000, which shows an ignition probability of 3% overall and of zero for large releases.

On the basis of this information, it is proposed that an ignition probability of 10% is used for total collapse and decouplement events.

C6 CONCLUSIONS

Frequencies of accidents involving total collapse and seal de-couplement of gas holders were derived from statistical treatment of historical data. The figures obtained in Section C2.1 are reported in Table C7.

The only accidents involving de-couplement and total collapse with ignition, recorded in the industry, have occurred several decades ago and no other such accidents have been reported since. Hence, estimates of frequency expectancy, excluding the past events have been derived through the application of the Poisson distribution model using the approximate numbers of gas holder years since nationalisation (1950) and for the whole accident free period (since 1930). An ignition probability of 50% for major accidents and a further 10% probability of total collapse were assumed in Reference 2 (these factors were applied in Section C2.2. However, as described in Section C3, the results obtained from recent historical data related to accidents experienced recently in gas holders, show that only 3% of gas leaks resulted in ignitions. Since 1970, 16 events resulting in gas releases greater than 30te were reported, however none of these ignited. This historical evidence suggests that the 50% ignition probability assumed above may be too conservative. Hence, an ignition probability of 10% is considered more realistic and was applied to derive the expected frequencies reported in Table C7. The table summarises frequencies obtained in this study through the analysis of historical data and through the application of the Poisson distribution as well as the corresponding figures derived in References 1 and 2.

Accidents involving total collapse and decoupled seal (or worse) with ignition	Frequency (cpm / holder / year)				
	From historical data on accidents		Estimates from Poisson distribution		
	Ref. 1	Calculated	Ref. 2 since 1950	Calculated since 1950	Calculated since 1930
All	~15	11.5	21	15	~9
Decoupled seal (or worse) with ignition	~10	5.7	10	~1.5	~0.9
Total collapse with ignition	~5	3.8	~1	~0.15	~0.1

Table C7 Comparison between predicted frequencies for accidents involving total collapse and decoupled seal (or worse).

REFERENCES

1 Revision of HSE's LUP assessment methodology for low pressure, water sealed, natural gas, gas holders. Part 4 – Decoupled seal and holder collapse events.

2 A Revised Three Zone LUP Siting Policy for Low Pressure, Water-Sealed Gas Gasholders Containing Natural Gas – Annex 2.

FIGURE C2 Events involving gas leaks from water-sealed gas holders between 1970 and 2000

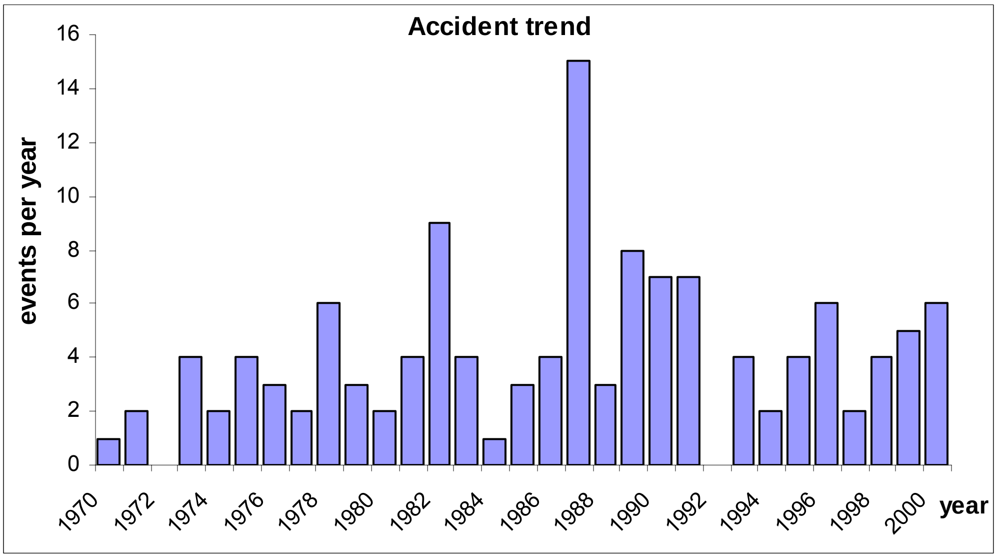


FIGURE C3 Frequency of leak per holder per during the operational years between 1970 and 2000

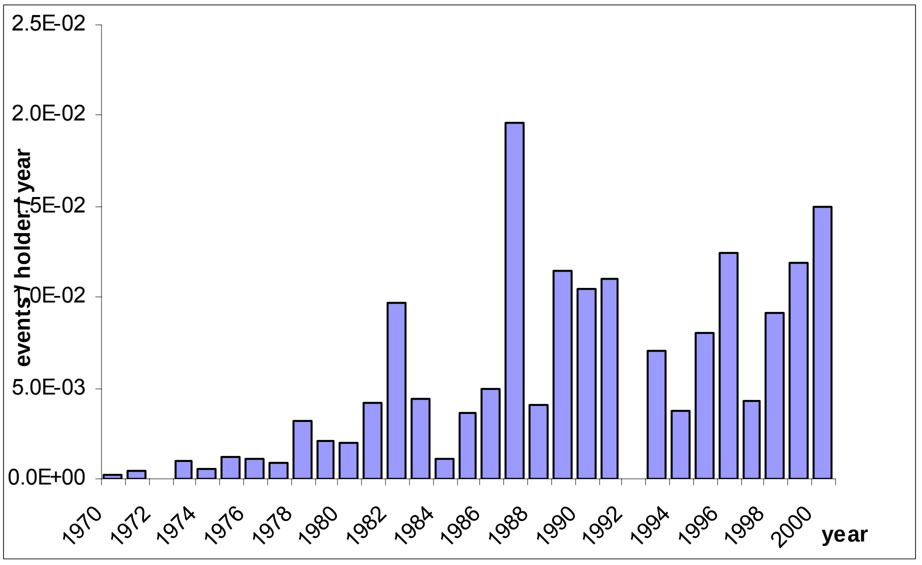


FIGURE C4 Causal distribution for gas holder events occurring between 1970 and 2000

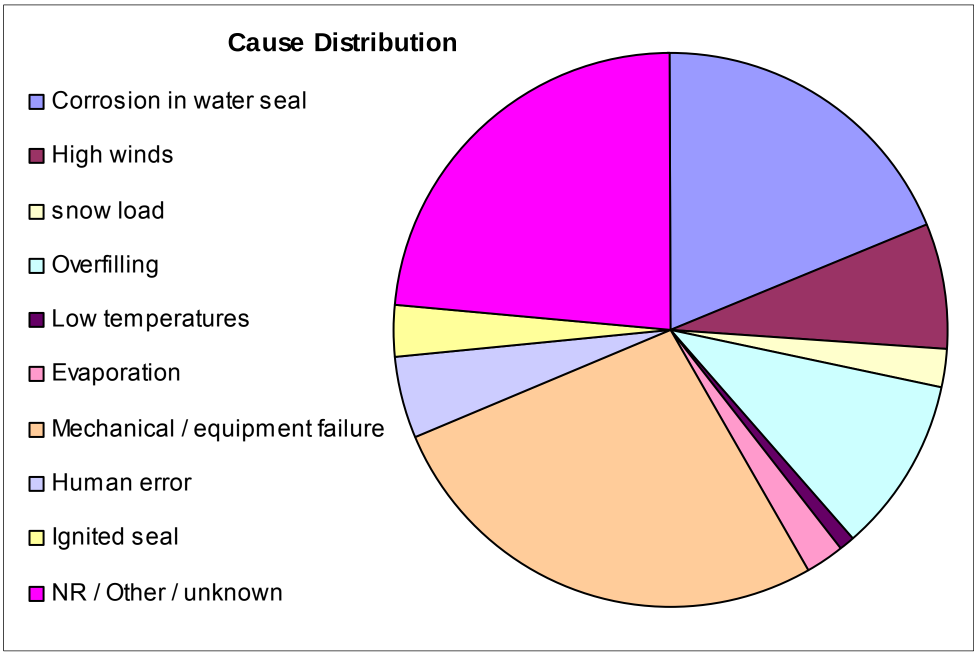


FIGURE C5 Release distribution for gas holder events occurring between 1970 and 2000

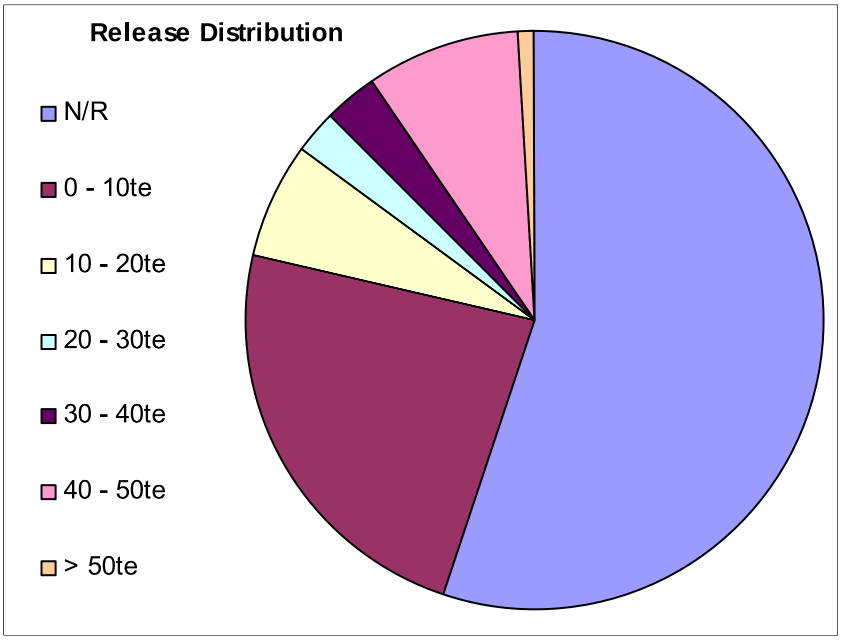
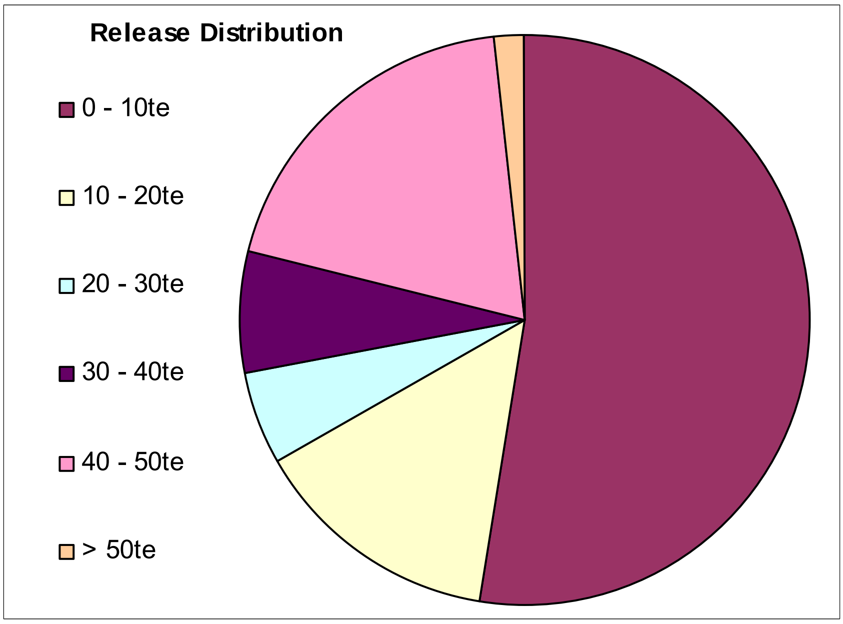


FIGURE C6 Release distribution for gas holder events occurring between 1970 and 2000 obtained by applying the severity distribution from quantified releases to un-quantified events



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