IGEM/TD/2 Edition 2
Communication XXXX

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Her Majesty the Queen

ASSESSING THE RISKS FROM HIGH PRESSURE NATURAL GAS PIPELINES

DRAFT FOR COMMENT

1 This draft Standard IGEM/TD/2 Edition 2 has been prepared by a Panel under the chairmanship of Jane Haswell.

2 This Draft for Comment is presented to Industry for comments which are required by 18th September 2012, and in accordance with the attached Reply Form.

3 This is a draft document and should not be regarded or used as a fully approved and published Standard. It is anticipated that amendments will be made prior to publication.

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The Organisations to which this Draft has been circulated are:

- AIGT
- BSi/GSE/33
- DNO Collaboration Forum
- Energy Institute
- ENA
- EUA
- EUSkills
- Gas Forum
- GIRSAP
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SECTION 1 : INTRODUCTION

1.1 This Standard revises and supersedes IGEM/TD/2, Communication 1737 which is obsolete.

1.2 This Standard has been drafted by a Panel appointed by the Institution of Gas Engineers and Managers' (IGEM) Gas Transmission and Distribution Committee, subsequently approved by that Committee and published by the authority of the Council of IGEM.

1.3 The Standard has been updated to more clearly differentiate between the assessments that would be undertaken by pipeline operators to justify the safe operation of the pipeline and assessments and those undertaken for land use planning purposes. Additionally, some of the technical information within the Standard, including risk reduction factors for concrete slab protection over pipelines and the risk reduction factors assumed for increased depth of cover over the pipeline have also been updated.

1.4 This Standard makes use of the terms "must", "shall" and "should" when prescribing particular requirements. Notwithstanding Sub-Section 1.9:

- the term "must" identifies a requirement by law in Great Britain (GB) at the time of publication
- the term "shall" prescribes a requirement which, it is intended, will be complied with in full and without deviation
- the term "should" prescribes a requirement which, it is intended, will be complied with unless, after prior consideration, deviation is considered to be acceptable.

1.5 IGEM/TD/1 Edition 5, Section 4 on planning and legal considerations, provides guidance on the route selection and location of new pipelines in various areas in terms of the acceptable proximity to significant inhabited areas.

IGEM/TD/1 Edition 5, Section 6 on design, categorizes locations adjacent to pipelines into Type R, S and T according to population density and/or nature of the immediate surrounding area.

IGEM/TD/1 Edition 5, Section 12 on operations and maintenance, provides requirements for surveillance and inspection which will reveal encroachment into areas of interest adjacent to a pipeline. Significant developments or infringements may require risk assessment using societal risk analysis for comparison with suitable risk criteria to allow the operator to assess whether the risks remain within acceptable limits.

IGEM/TD/1 Edition 5, Appendix 3 on risk assessment techniques, describes the application of risk assessment and includes a description of societal risk assessment with a sample of an actual F-N criterion based upon extensive application of previous editions of IGEM/TD/1. IGEM/TD/2 aims to support pipeline operators when carrying out risk assessments to assess safety risks associated with planning developments in close proximity to pipelines.

1.6 The general approach to the risk assessment process follows the stages outlined in IGEM/TD/1 Edition 5 Appendix 3. IGEM/TD/2 includes guidance on:

- determining failure frequencies
- consequence modelling
- standard assumptions to be applied in the risk assessment methodology
- conducting site-specific risk assessments
- risk reduction factors to be applied for mitigation methods
- benchmark results for individual and societal risk levels.

This Standard provides guidance for the risk assessment of major hazard pipelines containing Natural Gas. The need for undertaking a pipeline risk assessment may typically arise as a result of the need to:

- assess hazards and risks in support of the pipeline operator's Major Accident Prevention Document (MAPD);
- assess the acceptability of a development or developments that do not comply with proximity requirements or the population density requirements of IGEM/TD/1;
- support operational changes to a pipeline e.g. uprating (increasing the operating pressure) of a pipeline;
- assess the risks associated with specific operational issues;
- assess the implications of a Land Use Planning Application (see below).

Under the Town and Country Planning Act in England and Wales, and the Town and Country Planning Act (Scotland) in Scotland, it is the Local Planning Authority's responsibility to determine the acceptability of individual planning applications including developments in the vicinity of high pressure gas pipelines. These decisions would take account of safety advice provided by the Health and Safety Executive (HSE). In coming to a decision the Local Authority would weigh local needs and benefits and other planning considerations alongside the HSE's advice. The HSE's advice on land use planning in the vicinity of high pressure pipelines is delivered through PADHI (planning advice for developments near hazardous installations). A summary of the HSE's risk methodology upon which the PADHI advice is based is provided in Appendix 3 of this document.

In the event of a Local Planning Authority determining that a planning application should not be allowed based on the HSE's advice, the developer may approach the pipeline operator or seek independent guidance on the measures that can be taken to further reduce the risk. Alternatively there may be pipeline risk reduction features at the location of the proposed development that were not fully taken into account by the Local Planning Authority or the HSE when applying PADHI. These could, for example, include sections of pipeline with wall thicknesses greater than the notified pipeline wall thickness. The approaches detailed in this document can be used to undertake further detailed quantitative risk assessments in relation to land use planning applications.

As outlined in Reference 19, the HSE take a different approach when assessing the acceptability of a proposed development that has not yet received planning permission compared with an existing development. Not allowing the development is seen by the HSE as being relatively inexpensive when compared to the costs entailed in requiring existing developments with similar risks to introduce remedial measures. Pipeline operators and developers need to be aware of these differences in approach when undertaking assessments in relation to land use planning applications. Further details on the HSE's approach for assessing the acceptability of proposed developments in the vicinity of high pressure pipelines are provided in Appendix 3.

The guidance in this document does not cover environmental risks.

1.7 An overview of this Standard's content is given in Figure 1.

The guidance in this Standard is provided for the benefit of pipeline operators, local planning authorities, developers and any person involved in the risk assessment of developments in the vicinity of existing high pressure Natural Gas pipelines. It is based on the established best practice methodology for pipeline risk assessment, and is intended to be applied by competent risk assessment practitioners.

Where significant numbers of people are exposed to the risk, the pipeline operator may wish to carry out risk assessment using societal risk analysis for comparison with suitable risk criteria to allow the operator to assess whether the risks remain within acceptable limits. Section 6 describes the application of societal risk, and includes reference to the recommended F-N envelope in IGEM/TD/1 Edition 5.

1.8 It is now widely accepted that the majority of accidents in industry generally are in some measure attributable to human as well as technical factors, in the sense that actions by people initiated or contributed to the accidents, or people might have acted better to avert them.

It is therefore necessary to give proper consideration to the management of these human factors and the control of risk. To assist in this, it is recommended that due cognisance should be taken of HSG48.

The primary responsibility for compliance with legal duties rests with the employer. The fact that certain employees, for example "responsible engineers", are allowed to exercise their professional judgement does not allow employers to abrogate their primary responsibilities. Employers must:

(a) Have done everything to ensure, so far as is reasonably practicable, that there are no better protective measures that can be taken other than relying on the exercise of professional judgement by "responsible engineers".

(b) Have done everything to ensure, so far as is reasonably practicable, that "responsible engineers" have the skills, training, experience and personal qualities necessary for the proper exercise of professional judgement.

(c) Have systems and procedures in place to ensure that the exercise of professional judgement by "responsible engineers" is subject to appropriate monitoring and review.

(d) Not require "responsible engineers" to undertake tasks which would necessitate the exercise of professional judgement that is beyond their competence. There should be written procedures defining the extent to which "responsible engineers" can exercise their judgement. When "responsible engineers" are asked to undertake tasks that deviate from this, they should refer the matter for higher review.

Note: The responsible engineer is a suitably qualified, competent and experienced engineer or a suitably qualified, competent and experienced person acting under his or her supervision, appointed to be responsible for the application of all or part of this Standard.

1.9 Notwithstanding Sub-Section 1.5, this Standard does not attempt to make the use of any method or specification obligatory against the judgement of the responsible engineer. Where new and better techniques are developed and proved, they should be adopted without waiting for modification to this Standard. Amendments to this Standard will be issued when necessary and their publication will be announced in the Journal of IGEM and other publications as appropriate.

1.10 Requests for interpretation of this Standard in relation to matters within its scope, but not precisely covered by the current text, should be addressed to Technical Services, IGEM, IGEM House, High Street, Kegworth, Leicestershire, DE74 2DA, and will be submitted to the relevant Committee for consideration and advice, but in the context that the final responsibility is that of the engineer concerned. If any advice is given by, or on behalf of, IGEM, this does not relieve the responsible engineer of any of his or her obligations.

1.11 As with any risk assessment, judgement has to be employed by the risk assessor at all stages of the assessment. IGEM/TD/2 is intended to support the application of expert judgement. The final responsibility for the risk assessment lies with the assessor, and it is essential that the assessor be able to justify

every key assumption made in the assessment and document these assumptions as part of the assessment.

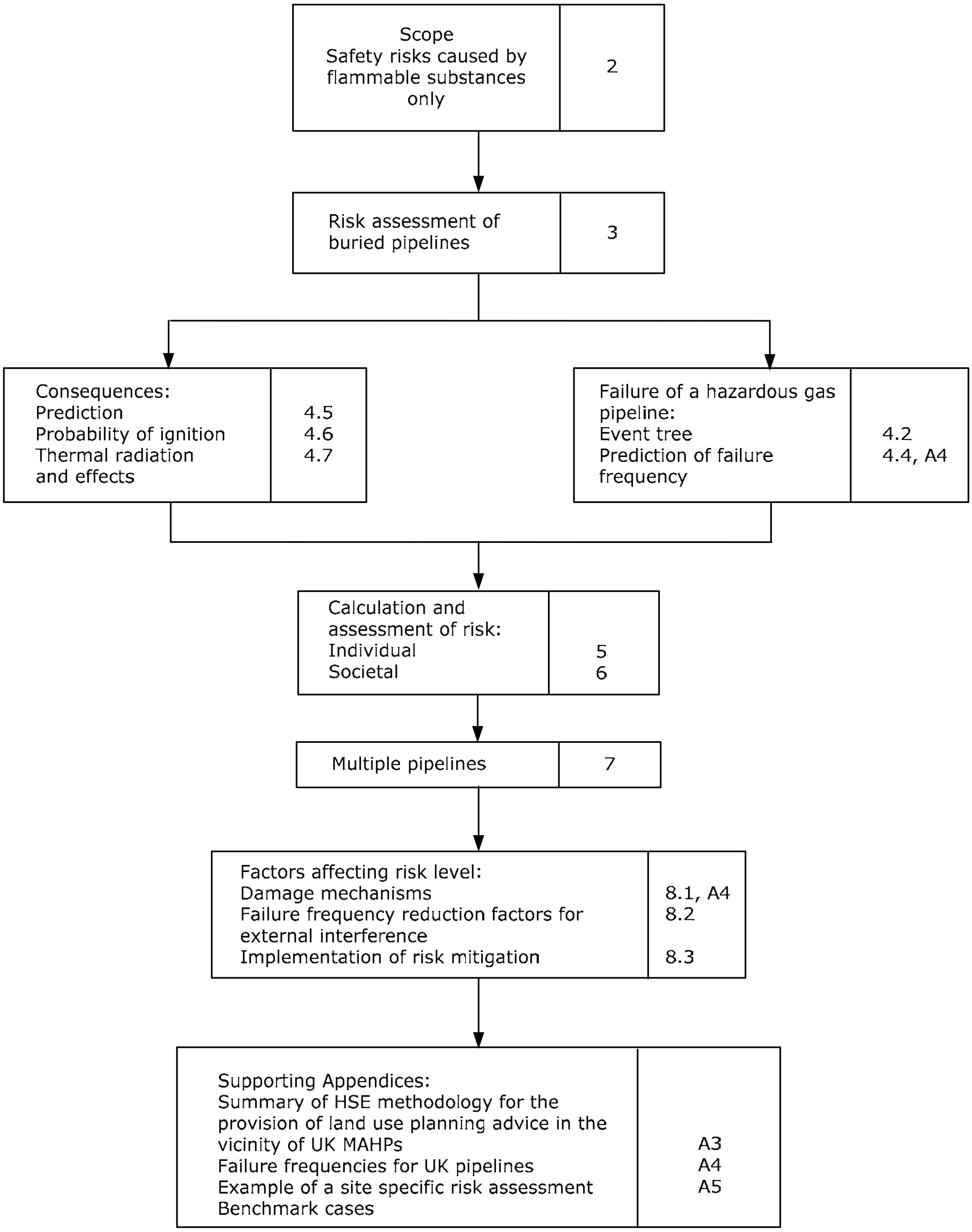


FIGURE 1 - OVERVIEW OF CONTENTS OF THE STANDARD

SECTION 2 : SCOPE

2.1 IGEM/TD/2 provides a framework for carrying out an assessment of the acute safety risks associated with major accident hazard pipelines (MAHPs) containing high pressure Natural Gas. It provides guidance on the selection of pipeline failure frequencies and on the modelling of failure consequences for the prediction of individual and societal risks.

The principles of this Standard are based on best practice for the quantified risk analysis of new pipelines and existing pipelines. It is not intended to replace or duplicate existing risk analysis methodology, but is intended to support the application of the methodology and provide guidance on its use.

2.2 This Standard is applicable to buried pipelines on land that can be used to carry high pressure Natural Gas, that is hazardous by nature, and therefore liable to cause harm to persons. It is limited to cross country pipelines and is not intended for application to pipelines and pipework forming part of above-ground installations, nor to associated equipment such as valves. The Standard does not cover environmental risks.

2.3 This Standard is intended for use in assessing the risks from high pressure gas pipelines including the additional risks that arise as a result of new developments in the vicinity of pipelines. This Standard provides a framework to help inform the pipeline operator on the acceptability, or otherwise, of these risks.

2.4 All references to gas pressure are gauge pressure, unless otherwise stated.

2.5 Details of all standards and other publications referenced are provided in Appendix 2.

Where standards are quoted, equivalent national and international standards, etc. equally may be appropriate.

2.6 Italicised text is informative and does not represent formal requirements.

2.7 Appendices are informative and do not represent formal requirements unless specifically referenced in the main sections via the prescriptive terms “must”, “shall” or “should”.

SECTION 3 : RISK ASSESSMENT OF BURIED PIPELINES - OVERVIEW

3.1 The failure of a pipeline containing Natural Gas has the potential to cause serious damage to the surrounding population, property and the environment. Failure can occur due to a range of potential causes, including accidental damage, corrosion, fatigue and ground movement. The safety consequences of such a failure are primarily due to the thermal radiation from an ignited release.

Quantified risk assessment (QRA) applied to a pipeline involves the calculation of risk resulting from the frequencies and consequences of a complete and representative set of credible accident scenarios.

In general terms, QRA of a hazardous Natural Gas pipeline consists of the following stages:

(a) Gathering data (pipeline and its location, meteorological conditions, physical properties of the substance, population) (Sub-Section 4.3).

(b) Prediction of the frequency of the failures to be considered in the assessment (Sub-Section 4.4).

(c) Prediction of the consequences for the various failure scenarios (Sub-Sections 4.5, 4.6, 4.7), including:
- calculation of release flow rate
- determination of ignition probability
- calculation of the thermal radiation emitted by fire in an ignited release
- quantification of the effects of thermal radiation on the surrounding population.

(d) Calculation of risks and assessment against criteria:
- estimation of individual risk (Section 5).
- estimation of societal risk (Section 6).

(e) Consideration of multiple pipelines (Section 7).

(f) Identification of site-specific risk reduction measures (Section 8).

Pipeline failure frequency is usually expressed in failures per kilometre year or per 1000 kilometre years. Failure frequency should be predicted using verified failure models and predictive methodologies (A2.3 Refs 1, 2, 3 and 4) or otherwise derived from historical incidents that have occurred in large populations of existing pipelines that are representative of the population under consideration, as recorded in recognised, published pipeline data (A2.3 Refs 5 and 6). Various factors may then be taken into account for the specific pipeline design and operating conditions to obtain the failure rate to be applied.

Note: Predictive models can be generated for all damage types and failure modes depending on the data available. In the UK, external interference is the dominant mode, and predictive models based on operational data are available (A2.3 Refs 1, 2 and 3). In general, failure frequency due to other damage types is typically derived using historical data (A2.3 Refs 5 and 6).

3.2 The consequences of pipeline failures should be predicted using verified mathematical models, the results validated using experimental data at various scales up to full or by comparison with recognised solutions, as well as comparison of model predictions with the recorded consequences of real incidents. The results of a consequence analysis should take into account all feasible events, in terms of the effective distance over which people are likely to become casualties. This should take into account people both outdoors and indoors.

3.3 Pipelines present an extended source of hazard, and can pose a risk to developments at different locations along their route. Where a length of pipeline over which a location-specific accident scenario can affect the population associated with a specific development, the full length over which a pipeline failure could affect the population or part of the population should be considered in the risk assessment. This length is known as "interaction distance" (see Sections 5 and 6).

SECTION 4 : FAILURE OF A HAZARDOUS GAS PIPELINE

4.1 GENERAL

Failure of a hazardous Natural Gas pipeline has the potential to cause damage to the surrounding population and property. Failure can occur due to a range of potential causes, including accidental damage, corrosion, fatigue and ground movement. The consequences of failure are primarily due to the thermal radiation that is produced if the release ignites.

4.2 FAILURE OF A NATURAL GAS PIPELINE

4.2.1 Failure of a high pressure Natural Gas pipeline is a leak or rupture caused by damage such as external interference, corrosion, fatigue or ground movement. Leaks are defined as gas lost through a stable defect; ruptures are defined as gas lost through an unstable defect which extends during failure to result in a full break or failure of an equivalent size in the pipeline. The escaping gas may ignite, resulting in a fireball and/or a crater fire or jet fire which generates thermal radiation. An event tree for the failure of a Natural Gas pipeline is shown in Figure 2.

4.2.2 If immediate ignition of a rupture release of gas occurs, a fireball can be produced which typically lasts for up to 30 s and is followed by a crater fire. If ignition is delayed by 30 s or more, it is assumed that only a crater fire will occur.

For the assessment of a rupture release, it is normally assumed that the ends of the failed pipe remain aligned in the crater and the jets of gas interact. However, under specific conditions, for example at a location close to a bend, it is possible for one or both pipe ends to become misaligned and produce one or two jets which are directed out of the crater and are unobstructed. Such releases can produce directional effects making their assessment more complex. Where such a location or pipe is being assessed, the standard case would normally be assessed and then the sensitivity of the location to directional releases reviewed. A more detailed assessment may then be required which would go beyond the standard methodology described in this Standard.

Note: For pipelines of diameter exceeding 300 mm, the standard assumption is that the pipe ends are aligned.

4.2.3 For high pressure Natural Gas pipelines, the release has a large momentum flux at the source and this normally has a significant vertical component. Natural Gas is lighter than air and so, over the normal range of transmission pipeline pressures, the jet or plume leaving the crater can be assumed to be buoyant. Hence, the possibility of a release of Natural Gas leading to a flammable mixture at ground level and a potential flash fire hazard affecting developments in the vicinity of a pipeline is highly unlikely.

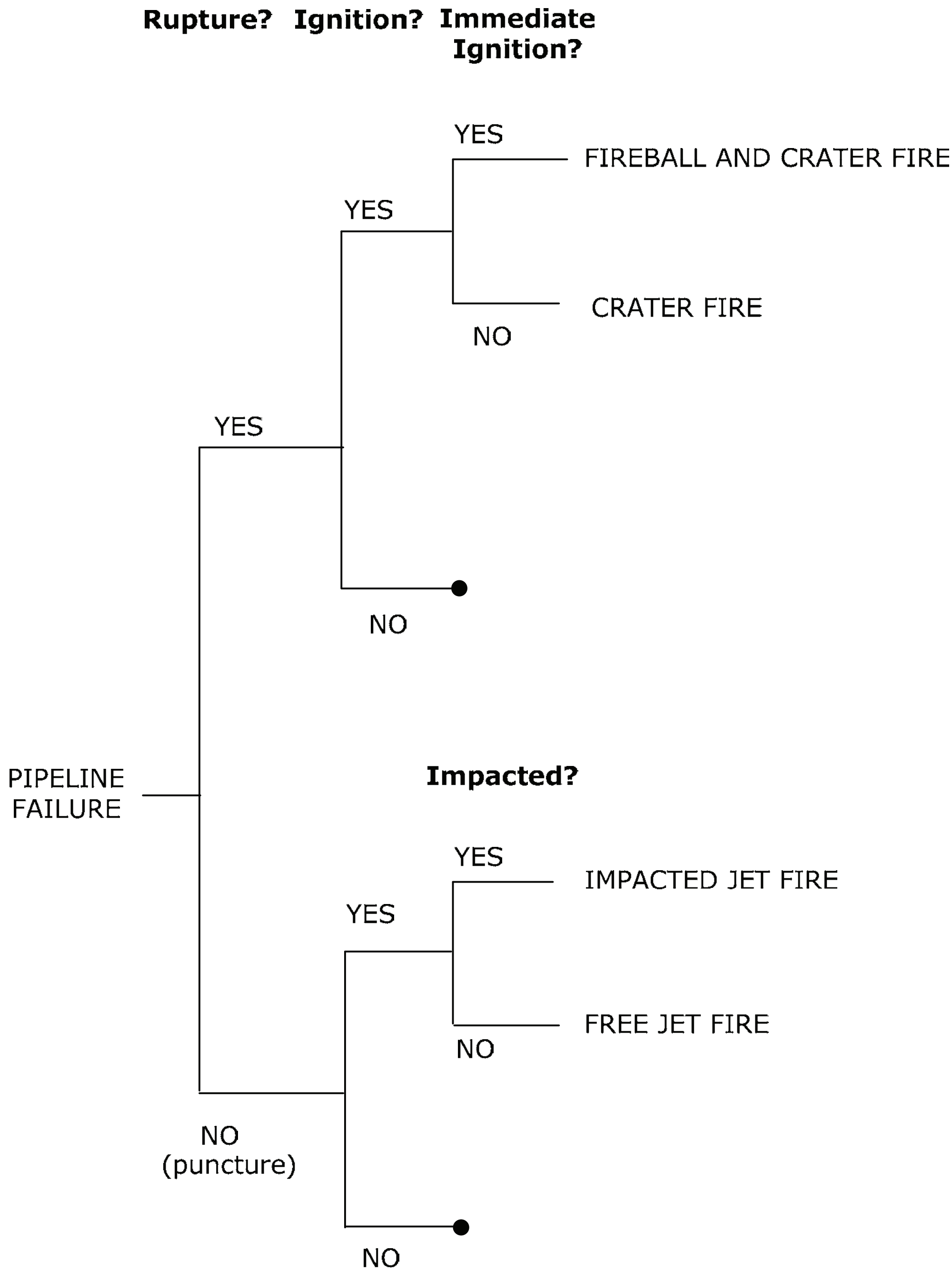


FIGURE 2 - EVENT TREE FOR A NATURAL GAS PIPELINE FAILURE

4.3 STAGES OF RISK ASSESSMENT

4.3.1 The stages of pipeline risk assessment are represented in Figure 3.

In general terms, a QRA of a Natural Gas pipeline should consist of 4 stages:

(a) input of data (pipeline and its location, meteorological conditions, physical properties of gas, population)

(b) prediction of failure mode and frequency for each credible failure cause

(c) prediction of consequences,
- calculation of release flow rate
- determination of ignition probability
- calculation of thermal radiation emitted by fire in an ignited release
- quantification of the effects of thermal radiation on the surrounding population

(d) calculation of risks.

4.3.2 The first stage of the risk assessment process is to gather the required data to characterise the pipeline, its contents and the surrounding environment. These data are used at various stages of the analysis. The data should be obtained from engineering records, operating data, the pipeline operating limits in the pipeline notification and from an examination of the pipeline surroundings.

The principle input data required for a pipeline QRA are:

- pipeline geometry – outside diameter; wall thickness
- pipeline material properties – for example grade, specified minimum yield strength (SMYS), tensile strength (TS), toughness (or Charpy impact value)
- pipeline operational parameters – maximum operating pressure (MOP), temperature, pipeline shut-down period and boundary conditions
- location details, including;
  - length and route of the pipeline to be assessed
  - area type (rural, suburban)
  - depth of cover
  - additional protection measures for the pipeline, for example concrete slabbing
  - details of any above- and below-ground pipeline marking
  - development and building categories in the vicinity and their distance from the pipeline
  - population and occupancy levels within the consequence range of the pipeline
  - road/rail crossing details, including traffic density
  - river crossings
- physical properties of the gas being transported, including information to characterise the pressure, volume and temperature behaviour of the gas throughout the range of conditions relevant to the analysis
- atmospheric conditions and wind speed and direction.

Any site-specific variations in the data should be assessed, and justifications for any additional assumptions to be applied locally should be documented. For depth of cover, site-specific depths should be taken into account. Where additional pipeline protection such as slabbing is to be taken into account, the design and installation should be assessed to ensure that additional loading is not imposed upon the pipeline, and direct contact should be maintained between the pipe coating and the surrounding soil.

The stages of pipeline risk assessment are schematically represented in Figure 3.

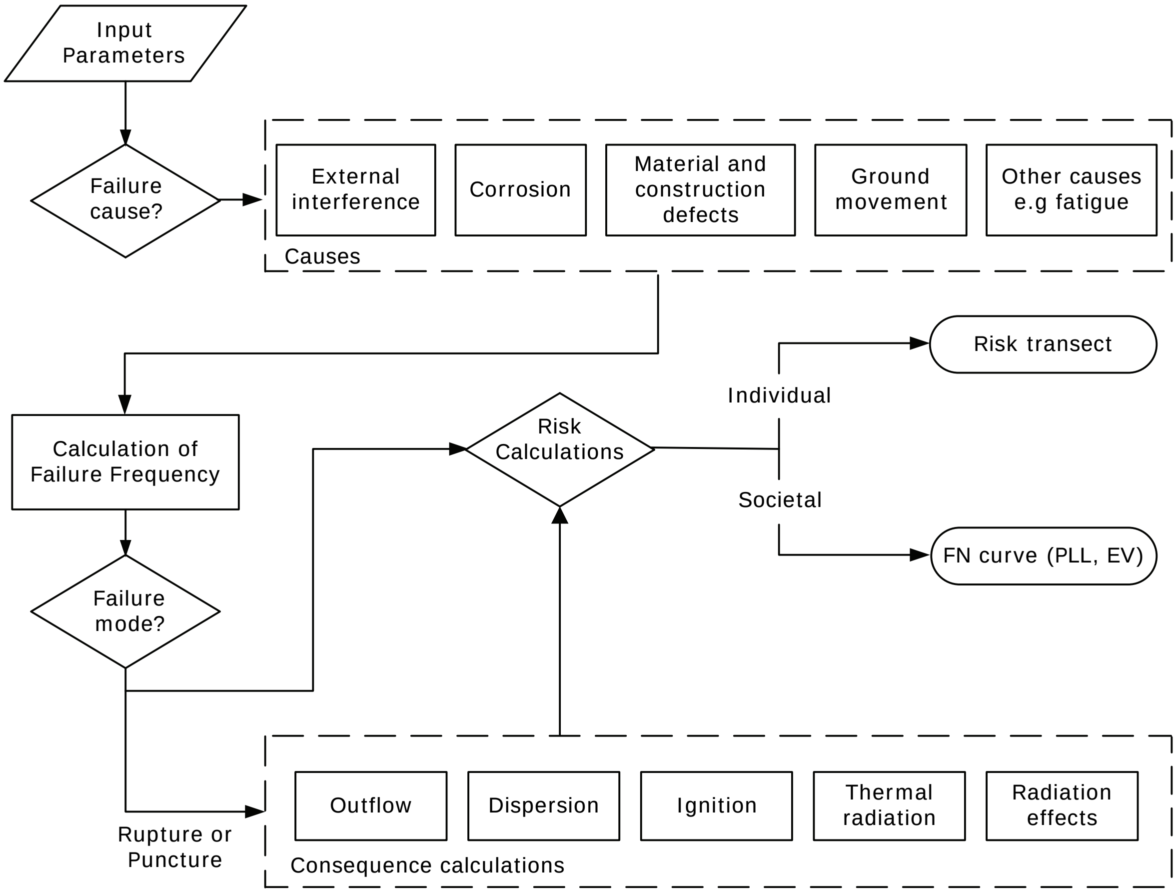


FIGURE 3 - THE STAGES OF PIPELINE RISK ASSESSMENT

4.4 PREDICTION OF FAILURE FREQUENCY

4.4.1 Failure of a pipeline can occur due to a number of different causes such as:

- external interference
- corrosion (internal and external, including stress corrosion cracking (SCC) and alternating current (AC)/direct current (DC) - induced corrosion)
- material or construction defects
- ground movement
- other causes, such as fatigue, operational errors etc.

The failure modes which should be considered include leaks and line breaks or ruptures. Leak sizes range from pinholes up to hole sizes which represent critical or unstable defects for particular pipeline parameters. Unstable defects result in ruptures. A rupture release is a full bore, double-ended break or equivalent from which gas is released into a crater from both sections of pipe. Typical failure frequencies for UK pipelines are given in Appendix 4.

Note: In most cases, the risk from natural gas pipelines will be dominated by the rupture scenario.

4.4.2 Leaks should be considered in terms of a specific range of hole sizes. Usually, failure frequency data is quoted for the sum of all hole sizes, and these should be classified into specific hole sizes to enable the risk assessment to be carried out. To determine the range of hole sizes to be considered in the consequence assessment, the hole size which gives an equivalent outflow to the critical length of an axial defect for specific pipeline parameters should be determined.

Typical hole diameters which are equivalent to critical defect lengths for high pressure Natural Gas pipelines (A2.3 Ref 7) are given in Appendix 4.

Note 1: Critical defect length and equivalent hole diameter applies to external interference where axial, crack-like defects can occur; the equivalent hole sizes which relate to such defects do not apply to rounded punctures or stable holes due to corrosion or material and construction defects.

Note 2: The maximum possible hole size in high pressure gas pipelines is limited according to the critical defect size.

Typical failure frequencies for UK MAHPs are given in Appendix 4. Where other data sources are used, these should be documented.

4.4.3 In a risk assessment, the likelihood of each failure scenario should be evaluated and expressed in terms of failure frequency and pipeline unit length. The usual form is to express the failure rate in terms of failures per kilometre per year, or per 1000 kilometres per year (equivalent to failures per million metres per year).

4.5 PREDICTION OF CONSEQUENCES

4.5.1 A consequence calculation should model and predict the transient gas release rate, the ignition probabilities, the characteristics of the resulting fire (fireball, and/or crater fire or jet fire), the thermal radiation field produced and the effects of the radiation on people and buildings nearby. Fires which should be considered as a result of ignition of a large gas release caused by a rupture are as follows:

- fireball, which occurs in the event of immediate ignition of a large gas release
- crater fire, which occurs in the event of delayed ignition of the gas flow released into the crater formed by the release, or following the immediate ignition fireball

Relevant references are A2.3 Refs 4 and 8 to 13.

4.5.2 The following aspects should be considered:

- outflow as a function of time (influenced by failure location and upstream and downstream boundary conditions). Pipeline rupture outflow requires complex calculations involving pressure reduction in the pipe (A2.3 Refs 4, 10, 12 and 13). Outflow from holes is calculated using conventional sharp-edged orifice equations for gas using a suitable discharge coefficient (A2.3 Ref 11)
- thermal radiation from the initial and reducing outflow into the fireball plume if the release is ignited immediately
- thermal radiation from jet and crater fires fed from reducing or steady state outflows.

Other consequences, which are generally found to be negligible compared to fire effects, include:

- release of pressure energy from the initial fractured section
- pressure generated from combustion during the initial phase if the release is ignited immediately
- missiles generated from overlying soil or from pipe fragments.

4.5.3 The consequence model should also consider:

- wind speed (often taken to be 2 m s^{-1} at night and 5 m s^{-1} during the daytime) which affects the fire tilt and, hence, the resulting radiation effects
- wind direction – only required for a site–specific risk assessment where wind direction will affect the populated area being considered in a non-uniform way
- humidity – this affects the proportion of thermal radiation absorbed by the atmosphere.

4.5.4 As observed in actual events and experimental research, if ignition occurs immediately on, or shortly after, a rupture, a transient fireball could occur. The fireball, which is the result of combustion of a mushroom-shaped cap that is fed from below by the established part of the fire, lasts typically for up to 30 seconds (depending on pipeline diameter and initial pressure).

4.5.5 In modelling fires following a rupture, the transient nature of the release should be modelled. This calculation requires an estimate of the initial and steady state release rates and an estimate of the inventory of the pipeline network which is discharging to the release point. For generic calculations, an assumption is that the break occurs half-way between a compressor station (or pressure regulating installation (PRI)) and the downstream compressor check valve or pressure regulating installation, with pressure being maintained from the upstream compressor station and no reverse flow occurring at the compressor station check valve or pressure regulating installation.

4.5.6 In modelling jet fires from punctures, the release can be considered to be steady-state. Usually the consequence model considers a vertical jet flame, with wind tilt created by the current wind velocity. More elaborate models are possible with different angles of flame. The consequences predicted by such models are increased directionally but the conditional probability is reduced.

4.6 PROBABILITY OF IGNITION

4.6.1 The risks from a pipeline containing flammable Natural Gas depend critically on whether a release is ignited, and whether ignition occurs immediately or is delayed. Generic values for ignition probability can be obtained from data from historical incidents.

A trend has been observed from analysis of historical data for rupture incidents where the ignition probability increases linearly with pd^2 (A2.3 Ref 14). The correlation derived for rupture releases takes the form:

$P_{ign} = 0.0555 + 0.0137\, pd^2;\ 0 \leq pd^2 \leq 57$

and

$P_{ign} = 0.81;\ pd^2 > 57$

P_{ign} = probability of ignition
p = pipeline operating pressure (bar)
d = pipeline diameter for ruptures (m)

The various ignition possibilities, together with the release types, are drawn out logically on an event tree (see Figure 2) to obtain overall probabilities (A2.3 Refs 10 and 14). Appropriate values for the probability of immediate or delayed ignition (and, if delayed, the assumed time(s) of ignition) should also be selected. The probability of ignition P_{ign} calculated as detailed above is then generally apportioned as 0.5 for immediate ignition and 0.5 for delayed ignition, where delayed ignition occurs after 30 seconds.

For puncture releases, the same ignition probability relationship may be applied, with d equal to the release hole diameter and with the pd^2 value halved, reflecting the difference between the two sources contributing to the gas release following a rupture and the single source contributing to a puncture release.

4.7 THERMAL RADIATION AND EFFECTS

4.7.1 Fatal injury effects are assumed for cases where people in the open air or in buildings are located within the flame envelope from a fireball, crater fire or jet fire. Outside the flame envelope, the effects are dependent on direct thermal radiation from the flame to the exposed person or building.

For crater fires, thermal radiation is highest at the flame surface and is attenuated with increasing distance as the view factor reduces and as heat is absorbed into the atmosphere.

Thermal radiation is calculated from the energy of the burning material. There are two main methods of calculation in use; the View Factor method which assumes a surface emissive power from the flame, and the Point Source method which assumes all the energy is emitted from one (or several) point sources within the flame. Usually the energy from the fireball pulse is calculated using the View Factor method.

The unit of thermal radiation dose is then defined as:

Thermal Dose Unit (tdu) = $(W)^{4/3} \times t$

W = flux = intensity of thermal radiation (kW m^{-2})
t = time (s).

Note: W is not independent of time for a transient release and is, normally, summed over exposure until safe shelter, the dose limit or a cut-off thermal radiation level of 1 kW m^{-2} for example, is recorded.

4.7.3 Experimental and other data indicate that thermal radiation dose levels can have different effects within a population depending on individual tolerance. The variation of effects has been estimated from burn data for human beings which suggests that the radiation level causing 50% fatal injuries in an average population can be taken as 1800 tdu. This level of thermal dose is often used in risk assessments. Developments such as schools, hospitals and old peoples' homes may be classed as "sensitive" developments due to the increased vulnerability of the population groups involved to harm from thermal radiation hazards. For such sensitive developments, where a more cautious approach may be appropriate, a casualty criterion of 1% lethality (corresponding to a "dangerous dose") should be applied as this corresponds to the 50% lethality level for this group of people. Such an approach allows sensitive developments to be included in an assessment of a wider mix of developments.

Note 1: The "dangerous dose" concept is defined as causing:
- *(a) severe distress to almost everyone in the area*
- *(b) a substantial fraction of the exposed population requiring medical attention*
- *(c) some people being seriously injured, requiring prolonged treatment*
- *(d) high-susceptible people being killed.*

Note 2: To assess safe escape distance, a number of factors need to be taken into account, including speed of escape for people outside running away from the fire, location and types of buildings, populations indoors, daytime and night, etc.

Note 3: HSE apply the 1000 tdu criterion for dangerous dose when determining the distances to the boundaries of the zones used to assess the acceptability of proposed new developments in the vicinity of high pressure pipelines, this is described in Appendix 3.

Note 4: For a more direct comparison with an assessment carried out by HSE for land use planning purposes, the assessment can be carried out using the dangerous dose level of thermal radiation for the whole population. Comparison with a societal risk acceptability criterion based on a higher level of thermal radiation will then be conservative for an average or mixed population.

4.7.4 The effects of the time-varying thermal radiation field generated by the fires (see sections 4.5.2 and 4.5.5) are quantified by assessing the variation of the thermal radiation field with time, typically by assessing the radiation at a series of times following ignition or from an equivalent steady state interpretation of the event, calculating the resultant dose levels for selected time intervals, then summing the thermal radiation dose received during the time of exposure at a fixed point, or by a moving target, in order to predict the effects on buildings and on persons who can attempt to escape from the effects of the fire. The distance from the fire at which buildings would burn, and also the distance at which persons are able to escape from the effects of the fire, are predicted based on either threshold ignition criteria for buildings and casualty criterion method or a probit equation method for persons. In the casualty criterion method, the thermal radiation predictions are used to calculate the distances at which the specified criteria are met.

The casualty criterion method does not directly account for the fact individuals within the population have a range of sensitivity to thermal radiation; however, this can be taken into account using a probit equation method. In this method, escape probability calculations are performed for each point on each escape path for each 1% band of the population in turn. These values are then integrated over the whole population to arrive at an overall casualty rate. In each method, the possibility that the escaping person may find shelter in a building beyond the building-burning distance can be accounted for.

Relevant references are A2.3 Refs 10, 17 and 18.

SECTION 5 : CALCULATION OF INDIVIDUAL RISK

Individual risk is a measure of the frequency at which an individual at a specified distance from a pipeline is expected to sustain a specified level of harm from the realization of specific hazards.

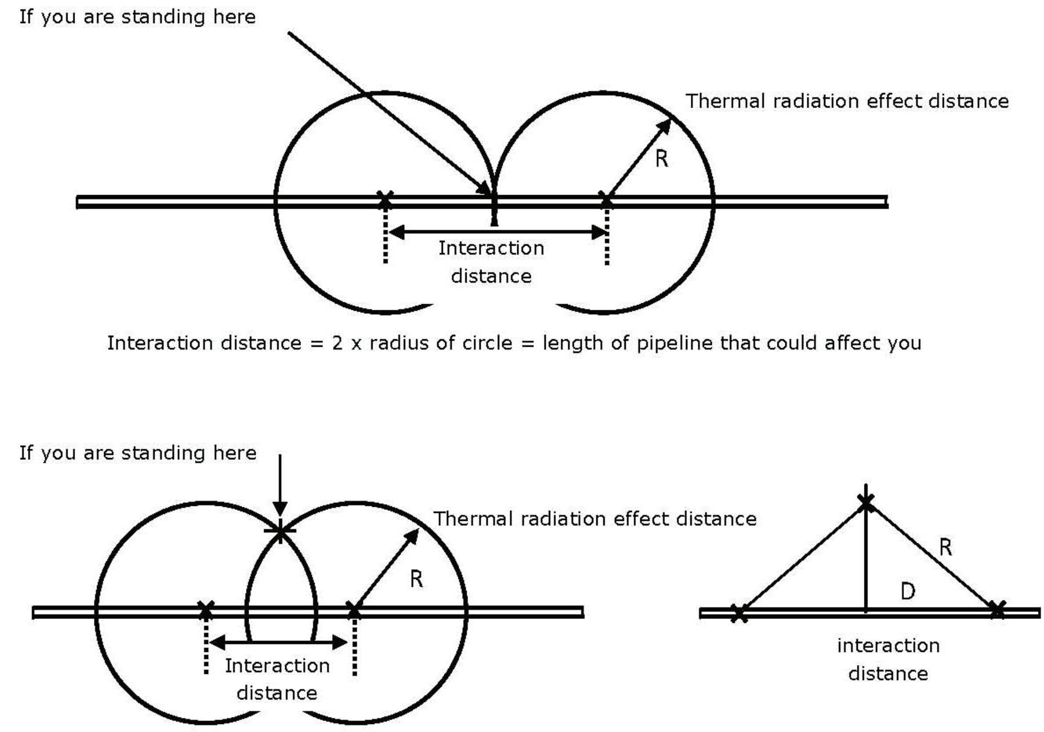
A simple explanation of the calculation of individual risk posed by pipelines is given in this section. Further detail may be found in the references listed in A2.3 (4,8,10,12). Risk calculations should be carried out by competent experts using appropriate, quality assured software.

Individual risk contours for pipelines of given geometry, material properties and operating conditions form lines parallel to the pipeline axis. The distance from the pipeline at which a particular level of risk occurs depends upon the pipeline diameter, operating pressure, frequency of failure and failure mode.

The risks from the various failure scenarios (ruptures and various holes sizes causing fireballs, crater fires and jet fires) should be collated and the individual risk profile at various distances plotted on a graph. From this plot, it is possible to identify the risk of a specific effect, for example fatality or dangerous dose, to an individual at a given distance from the pipeline. Shown in cross-section perpendicular to the pipeline, the risk levels are known as the risk transect.

Pipelines present a hazard along the pipeline route and, therefore, the full length over which a pipeline failure could affect any specific location should be considered in the risk assessment. This length is known as the interaction distance.

For a simple model where wind speed conditions are zero, the consequences are circular and the interaction distance is calculated as shown in Figure 4. The interaction distance shown can be multiplied by the pipeline failure frequency, the probability of ignition and the consequences (thermal radiation and casualty criteria) to obtain the risk at any distance from the point of release. Distances to specified Individual Risk levels can be obtained from the Risk Transect.



interaction distance = $2x\sqrt{(R^2 - D^2)}$

FIGURE 4 - CALCULATION OF PIPELINE LENGTH WHICH CAN AFFECT AN INDIVIDUAL AT VARIOUS DISTANCES FROM A PIPELINE

Criteria for individual risk levels have been determined by HSE in the UK. The framework for the tolerability of individual risk published by HSE, based on historical risk of death (see A2.3 Ref 13), is shown in Figure 5.

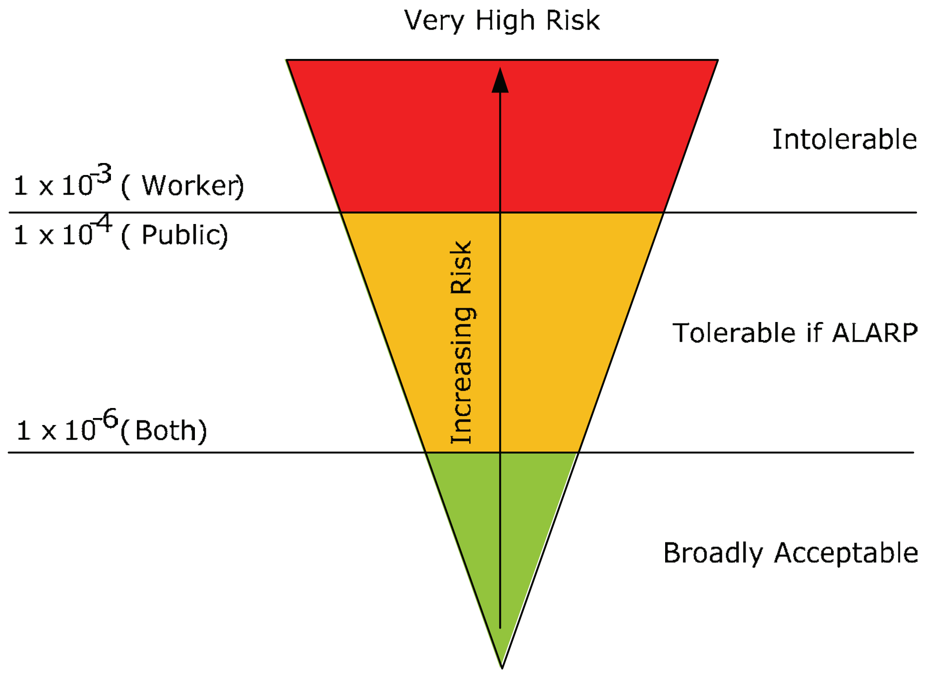


FIGURE 5 - HSE FRAMEWORK FOR TOLERABILITY OF RISK

HSE sets land use planning zones for major hazard sites, including high pressure pipelines transporting defined hazardous substances based on the individual risk levels for dangerous dose. Three risk-based zones, the inner, middle and outer zones, are defined by HSE based on the “dangerous dose or worse”. The outer zone is defined as the consultation distance within which the risk implications of planning developments should be considered by the Local Planning Authority (LPA). Land use planning zones applied to major accident hazard pipelines in the UK defined by HSE are discussed in Appendix 3.

SECTION 6 : CALCULATION OF SOCIETAL RISK

6.1 Societal risk is a measure of the relationship between the frequency of an incident and the number of casualties that will result. Societal risk can be generic, in which a constant distributed population in the vicinity of the pipeline is assumed, or site-specific, in which the details of particular developments, building layout and population distributions are taken into account. Site-specific assessments are needed for housing developments, industrial premises, workplaces such as call centres, commercial and leisure developments, and any development involving sensitive populations.

6.2 The hazards associated with high pressure Natural Gas pipelines tend to be high consequence, low frequency events, and societal risk is generally the determining measure for the acceptability of pipeline risk. The calculation is carried out by assessing the frequency and consequences of all of the various accident scenarios which could occur along a length of pipeline.

6.3 Societal risk is typically expressed graphically using an F-N curve showing the cumulative frequency F (usually per year) of accidents causing N or more casualties. For application to pipelines, it is necessary to specify a length over which the frequency and consequences of all accident scenarios are collated. Application of IGEM/TD/1 has been shown to result in a residual societal risk and this is expressed as a criterion F-N envelope in Figure 6. This criterion is calculated from the residual risk to a range of generic R area cases at the limited design factor and population density and for S area cases at the limiting design factor and for typical population densities. The envelope was drawn around the resultant family of approximately rectangular shaped F-N curves and was subjected to As Low As Reasonably Practicable (ALARP) considerations. In effect, it is a practical representation of the 'broadly acceptable' limit of a typical code-compliant pipeline route.

Note 1: This envelope has been generated using a methodology which incorporated thermal radiation dose of 1800 tdu (50% fatality) for the casualty criterion to assess population effects.

Note 2: The methodology applied must be consistent with the criterion used in assessment of results.

Note 3: The IGEM/TD/1 F-N criterion envelope represents broadly acceptable risk levels in both R and S Areas.

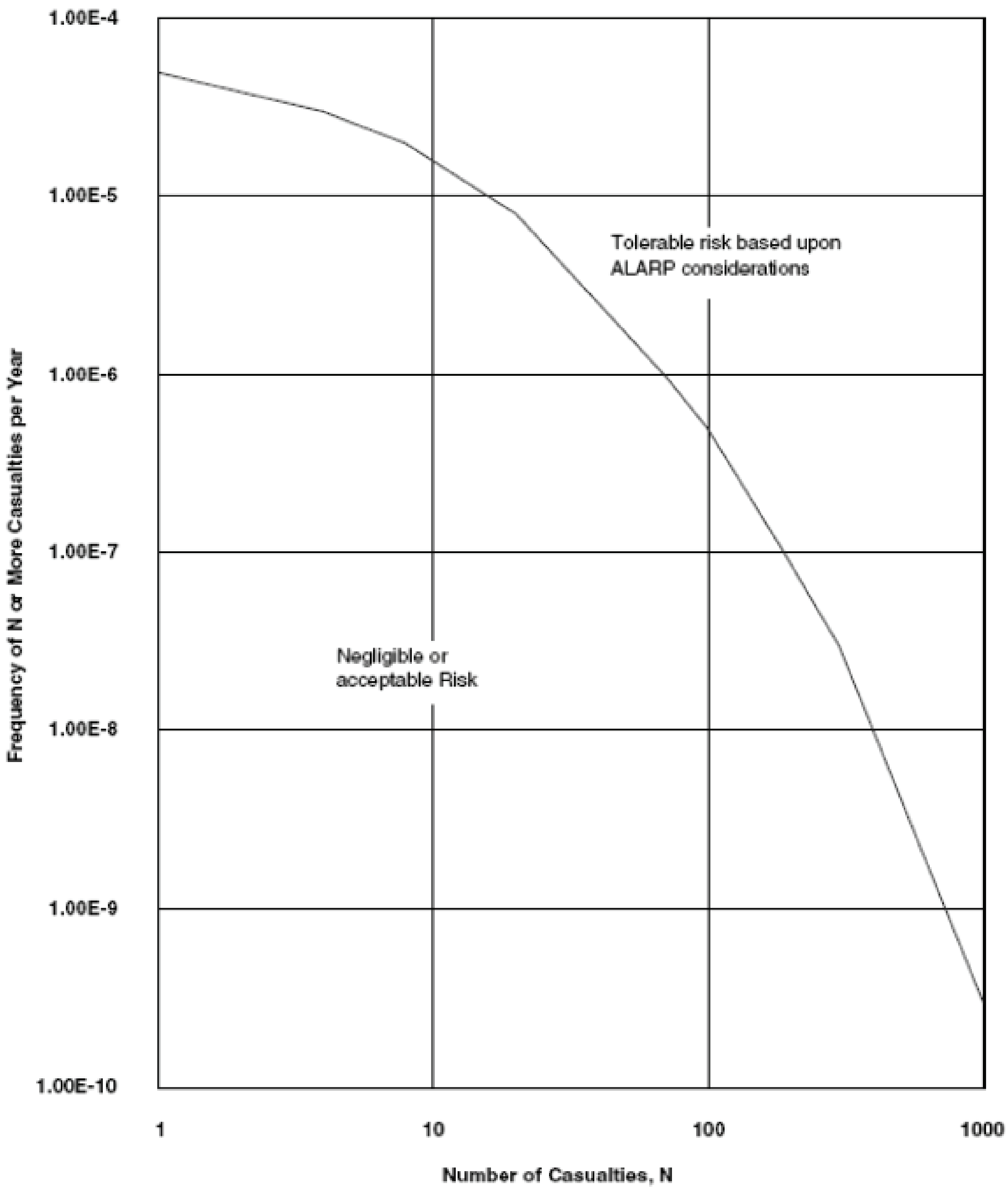


FIGURE 6 - F-N CRITERION BASED ON EXTENSIVE APPLICATION OF IGEM/TD/1

6.4 Societal risk is of particular significance to pipeline operators and the impact of multiple fatality accidents on people and society in general. The original routing of the pipeline is expected to have taken into account the population along the route, but “infill” and incremental developments may increase the population in some sections of the route. Societal risk assessment allows these developments to be assessed against the original routing criteria. When societal risk has increased significantly, the pipeline operator may need to consider justifiable mitigation measures to reduce risk.

Because of the dominance of the rupture failure mode, F-N curves from typical R area assessments of minor code infringements and land use planning cases are fairly close to rectangular in shape. This will also apply to many S area assessments. However, some smaller diameter pipelines and/or complex S area

locations can produce F-N curves which differ from this approximately rectangular shape. Particular care will be required in assessing the results in these cases (see Sub-Section 6.7).

6.5 Usually, population density is not equally spread so, in some cases, “clusters” of population occur along a pipeline route. Assessment of the societal risk in accordance with the F-N envelope may still allow this to be classified as an acceptable situation not requiring any upgrading of the pipeline to reduce the risk. It is recommended that this form of assessment is carried out on an ongoing basis to ensure that the risks due to developments and changes occurring near the pipeline are monitored, quantified and managed.

Note: Societal risk assessment provides an operator's view on the acceptability of a development in the vicinity of a pipeline, which takes account of other developments in the vicinity of the pipeline.

6.6 The methodology for considering and assessing risk scenarios, failure cases, failure frequencies and consequences is similar to that used to obtain individual risk levels.

6.7 To carry out a site-specific societal risk assessment, the maximum distance over which the worst case event could affect the population in the vicinity should be determined, for example the site length combined with the escape distance for thermal radiation (see Figure 6). This is defined as the site interaction distance.

6.8 The accident scenarios which are relevant for the pipeline section within the site interaction distance should be listed and the actual population density within the area of interest should be determined. The frequency, f, and effect area for each accident scenario is then assessed at points along the site interaction distance, and the number of people, N, who would be affected, is determined at a specific location. This provides a number of f-N pairs, which are then ordered with respect to increasing number of casualties, N, and the cumulative frequency, F of N of more people being affected is determined, giving a site-specific F-N curve.

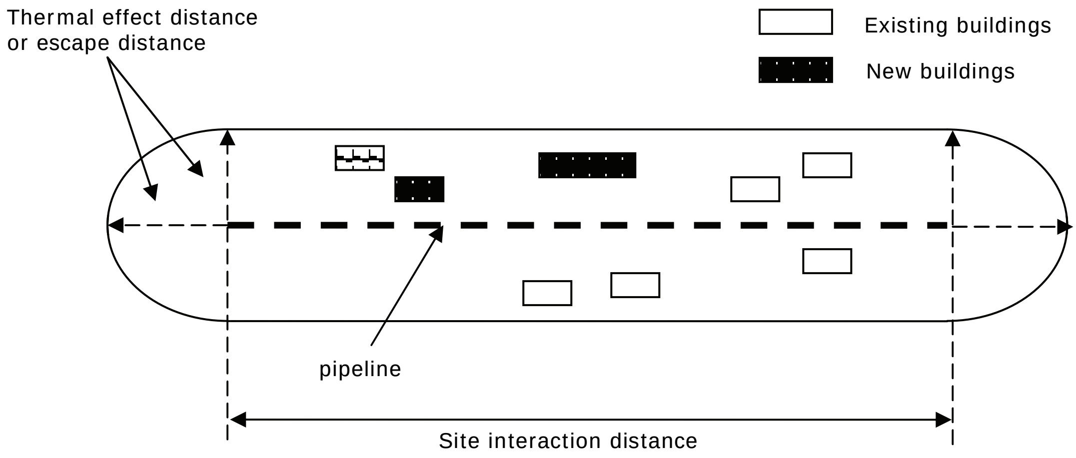


FIGURE 7 - SITE-SPECIFIC PIPELINE INTERACTION DISTANCE FOR SOCIETAL RISK

6.9 The site-specific F-N data should be compared to the IGEM/TD/1 Edition 5 F-N criterion envelope. As the IGE TD/1 criterion envelope relates to a 1.6 km length of pipeline, the site-specific F-N criterion is obtained by factoring risk values by a value equal to 1.6 km divided by the site interaction distance.

6.10 The IGEM/TD/1 Edition 5 F-N criterion envelope represents broadly acceptable risk levels for pipeline routing. If the calculated site-specific F-N curve (which on a log F against log N plot would be expected to be generally rectangular in shape) is below the IGEM/TD/1 Edition 5 F-N criterion envelope, the risk levels to the adjacent population are considered broadly acceptable. An ALARP check may also be carried out as confirmation. If the site-specific F-N curve is far from the expected generally rectangular shape and cannot be approximately contained by a rectangle based on a point on the envelope, or approaches close to, or exceeds, the F-N criterion envelope, an ALARP demonstration will be required. Further mitigation may then be required to reduce risks to acceptable levels or the proposed development may be deemed unacceptable.

6.11 Where the methodology used in the assessment differs from that described in this Standard, and cannot be demonstrated to be conservative, an additional check should be made by assessing a relevant range of code compliant pipelines using the same methodology to locate the approximate position of the F-N envelope.

SECTION 7 : MULTIPLE PIPELINES

7.1 If the specified area of interest includes another pipeline, the risk from this pipeline should be included in the assessment.

7.2 If pipeline interaction is considered likely, then expert opinion should be obtained on how to model the combined failure frequencies and gas outflow. Guidance is given in IGEM/TD/1 Edition 5 on the minimum separation distances for gas transmission pipelines to avoid interaction in the event of a failure.

7.3 When assessing multiple pipelines that do not interact, F-N data should be obtained for each pipeline in the area of interest. To calculate the overall risk it is necessary to sum the cumulative F-N data from each assessment. This data must then be factored by a value equal to 1.6 km multiplied by the number of pipelines, divided by the sum of the interaction lengths, and compared to the IGEM/TD/1 F-N criterion curve.

SECTION 8 : FACTORS AFFECTING RISK LEVEL

8.1 DAMAGE MECHANISMS

8.1.1 All the key damage mechanisms should be taken into account when carrying out a risk assessment. Typical causes classified in databases include:

- external interference
- mechanical failure, including material or weld defects created when the pipe was manufactured or constructed
- ground movement, either natural, for example landslide or man-made, for example excavation, mining
- corrosion, either internal or external
- operational, due to overpressure, fatigue or operation outside design limits
- other – several other causes are recorded.

Assessment of pipeline failure databases shows that external interference and ground movement dominate pipeline rupture rates and pipeline ruptures dominate the risk. The failure rates due to other damage mechanisms may be managed and controlled by competent pipeline operators through testing, inspection, maintenance and operational controls in accordance with IGEM/TD/1 Edition 5 Section 12, and are therefore assumed to be negligible.

8.1.2 The failure rate for external interference is influenced by a number of parameters including the pipeline wall thickness, design factor and material properties as well as the area type, the pipeline depth of cover and the local installation of pipeline protection such as slabbing.

The failure rate for natural ground movement and for man-made ground movement depends upon the susceptibility to landsliding or subsidence at the specific location.

In some cases, other causes may need to be considered, such as the quality of girth welds, the potential for SCC or AC/DC-induced corrosion.

8.1.3 The failure frequency associated with each damage mechanism should be determined using recognised published operational data sources (see A2.3 Refs 5 and 6), or predictive models validated using such data. Recommended failure frequencies for UK pipelines based on United Kingdom Onshore Pipeline Operators Association's (UKOPA's) data are given in Appendix 4.

The effect of risk reduction measures should only be taken into account for the damage mechanism that would be affected by those measures, for example the reduction in failure frequency due to increased depth of cover or slabbing should only be applied to the external interference damage contribution of the total failure frequency.

8.1.4 The risk analysis requires the data described in Section 4. Any site-specific variations should be assessed and the justification for any additional assumptions to be applied locally should be documented. For depth of cover, site-specific measurement should be taken into account. Where additional pipeline protection such as slabbing is to be taken into account, the design and installation of the slabbing should be assessed to confirm it is in accordance with the UKOPA specification for installation of slabbing for pipeline protection (A2.3 ref 28). In particular, the design should be assessed to ensure that it is sufficiently wide to guard against lateral encroachment and it should be sufficiently thick to prevent it being breached by the majority of common excavating machinery (see note). The design should also ensure that the

additional loading is not imposed upon the pipeline, and cathodic protection (CP) is maintained.

Note: *Because of the size and power of modern large scale excavating and boring equipment, it is not practical to design slab protection that is capable of guaranteeing that the pipeline will never be damaged by all machinery. However the slab should be designed that it is capable of protecting the pipeline from the majority of types of machinery that can be reasonably foreseen as potentially operating in the vicinity of the pipeline.*

8.1.5 In determining the external interference failure frequency, account should be taken of the area classification, i.e. R or S. The damage incidence or hit rate for S areas should be assumed to be higher than that for R areas. Typically, the factor applied is approximately 4 times that in rural areas, i.e. the failure frequency in an S area is 4 times that in an R area. Data relating to relevant R and S area incident rates data is provided by UKOPA (A2.3 Ref 5).

The failure rates obtained from database records or predictive models should be justified for application to a site-specific case. Generic failure data may not be applicable to specific cases. Information is given in Appendix 4.

8.2 FACTORS FOR REDUCTION OF THE EXTERNAL INTERFERENCE FAILURE FREQUENCY FOR USE IN SITE-SPECIFIC ASSESSMENTS

8.2.1 The primary residual risk for existing pipelines is that due to external interference. Relevant reduction factors for failure frequency due to external interference and other damage mechanisms should be taken into account in site-specific risk assessments. Risk mitigation measures should be identified and agreed as necessary by the statutory authority or relevant stakeholder. These should be installed prior to the completion and use of any new development within the pipeline consultation zone. Risk mitigation measures fall into two categories, i.e. physical and procedural. Procedural measures rely upon management systems and can be subject to change over time, and therefore might only be applicable for short-term risk control.

Physical measures include:

- wall thickness and design factor
- slabbing
- depth of cover.

Procedural measures include:

- additional surveillance
- additional liaison visits
- additional high visibility pipeline marker posts.

8.2.2 A site-specific risk assessment should take into account relevant details of the pipeline and should document justification of any assumptions applied following assessment of these details.

Note: *A site-specific risk assessment and typical bench mark solutions are given in Appendices 5 and 6.*

8.2.3 The pipeline failure frequency (F) due to external interference is obtained as follows:

$$F = PoF \times I/OE$$

F	=	pipeline failure frequency
PoF	=	pipeline probability of failure
I	=	number of incidents of external interference events causing damage (including failure) in a given pipeline population
OE	=	operational exposure (km yr)
I/OE	=	damage incidence rate.

Note: The damage incidence rate and the operational exposure relate to the population that the pipeline is part of, not just the pipeline itself. Pipeline failure frequencies derived from published operational data sources are given in Appendix 4.

In deriving the site-specific pipeline failure frequencies for external interference, the parameters listed in clause 4.3.2 should be taken into account. A number of factors which describe the specific effects of wall thickness and design factor on the pipeline probability of failure and depth of cover, surveillance frequency and damage prevention measures (slabbing and marker tapes) and damage incidence rate are presented here. These factors can be used to assess the effect of individual measures on a known or existing unadjusted pipeline failure frequency for a particular pipeline or, to obtain a failure frequency prediction for a given pipeline, appropriate factors can be applied cumulatively to the base failure frequency for the particular pipe diameter as shown in Appendix 4.

8.2.4 The influence of specific parameters on the predicted pipeline failure frequencies is given as reduction factors as follows:

- R_{df} - reduction factor for design factor, given in Figure 7
- R_{wt} - reduction factor for wall thickness, given in Figure 8
- R_{dc} - reduction factor for depth of cover, given in Figure 9
- R_s - reduction factor for surveillance frequency, given in Figure 10
- R_p - reduction factor for protection measures given in Table 2.

Note: The HSE do not currently take account of all of the above factors when assessing the acceptability of proposed developments in the vicinity of high pressure pipelines, see Appendix 3 for more details.

Figures 8 and 9 show simple reduction factors for design factor and wall thickness which can be used in estimating the failure frequency due to external interference. These two reduction factors have been derived from the results of comprehensive parametric studies (A2.3 Refs 20 to 22) carried out using models which describe the failure of a pipeline due to gouge and dent-gouge damage (A2.3 Refs 23 to 25), and damage statistics derived from the UKOPA pipeline database (A2.3 Ref 5). The reduction factors take the form of a factor for design factor and a factor for wall thickness, that are applied either to a predicted pipeline PoF or to a failure frequency predicted for a specific pipeline using a specific damage incidence rate. The range of pipeline parameters over which the reduction factors are applicable is given in Table 1.

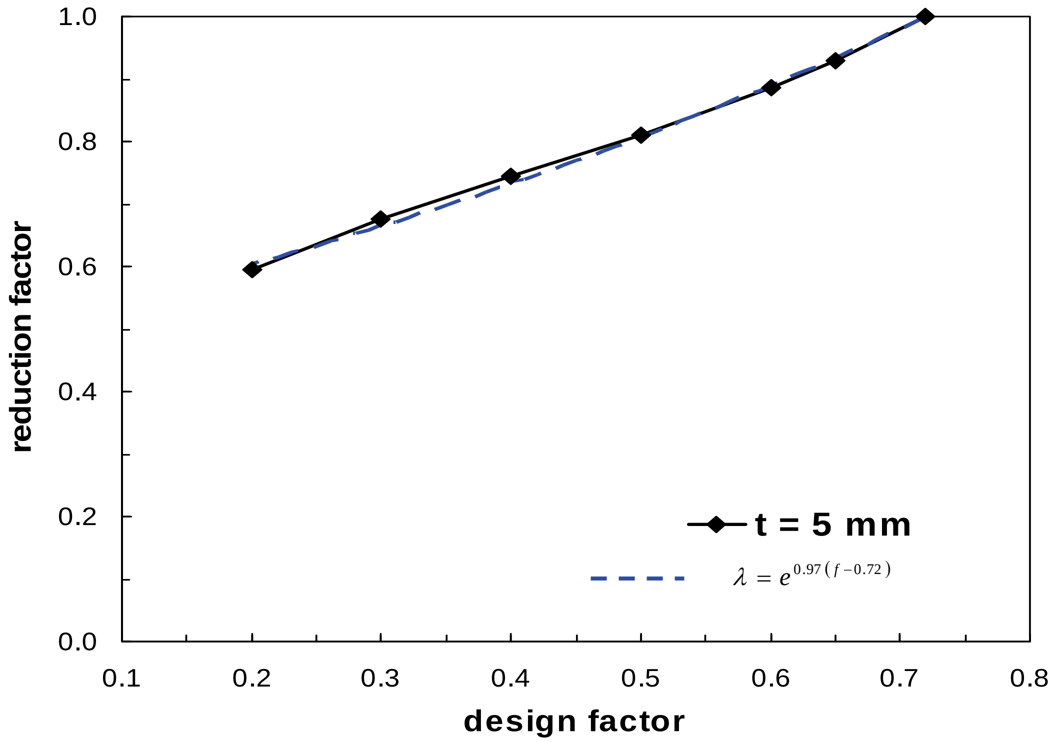


FIGURE 8 - REDUCTION IN EXTERNAL INTERFERENCE TOTAL FAILURE FREQUENCY DUE TO DESIGN FACTOR

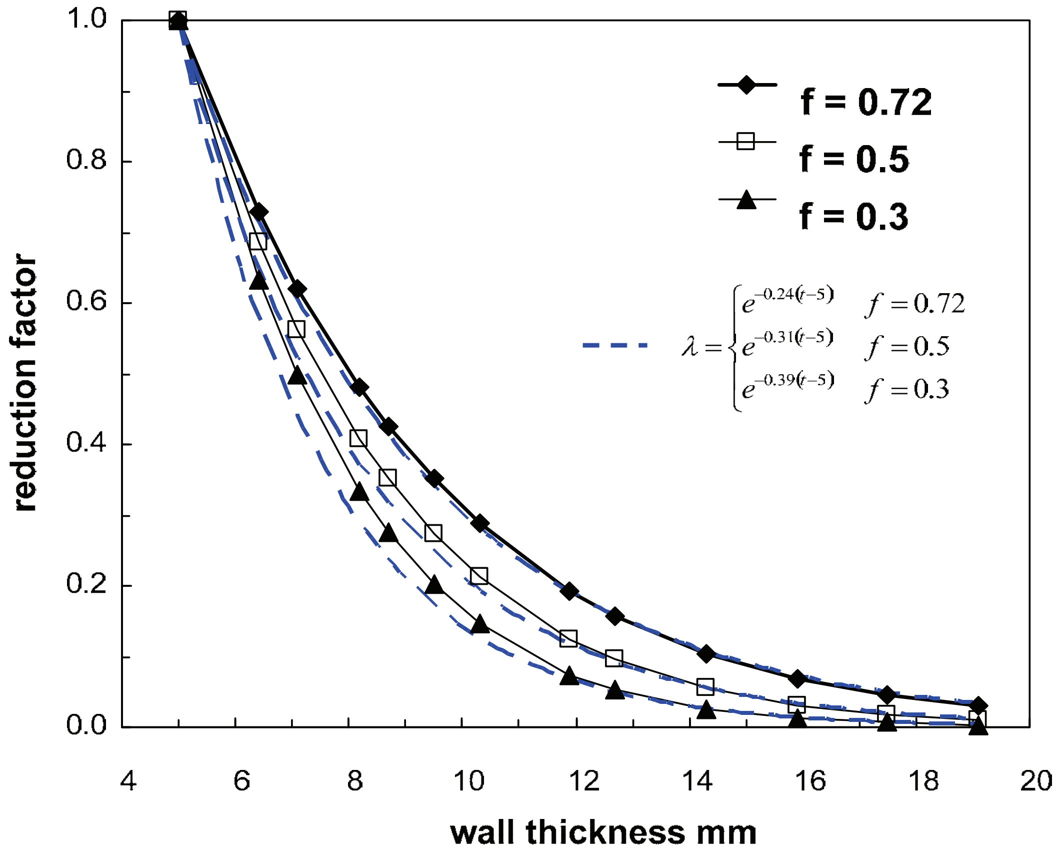


FIGURE 9 - REDUCTION IN EXTERNAL INTERFERENCE TOTAL FAILURE FREQUENCY DUE TO WALL THICKNESS

PARAMETER	RANGE OF APPLICABILITY OF DESIGN FACTOR AND WALL THICKNESS REDUCTION FACTORS
Design factor	≤ 0.72
Wall thickness	≥ 5 mm ≤ 19.1 mm
Material grade	≤ X65
Diameter	219.1 to 914.4 mm
Charpy Energy	≥ 24 J (average)

TABLE 1 - RANGE OF APPLICABILITY OF DESIGN FACTOR AND WALL THICKNESS REDUCTION FACTORS

The reduction factors given in Figures 8 and 9 are based on a conservative interpretation of the parametric study results. Where the pipeline parameters fall outside the range given for the applicability of the reduction factors in Table 1, the reduction factors should not be applied and a case specific analysis should be carried out using an appropriate failure frequency prediction model. They may be applied separately to modify existing risk assessment results i.e. to modify existing risk assessment results taking into account local changes in wall thickness, or may be used more comprehensively to estimate the failure frequency in screening risk assessments, using both reduction factors in conjunction with the generic failure frequency curve in Appendix 4 as an alternative to using more complex structural reliability based methods. Further details are given in Appendix 4.

Figure 10 shows a simple reduction factor for depth of cover which can be used in the estimation of the failure frequency due to external interference. This reduction factor has been derived from the results of work carried out by GL Nobel Denton for UKOPA (see A2.3 Ref 26). Use of this reduction factor places a requirement on the pipeline operator to carry out and document periodic checks to confirm the depth of cover is being maintained (see clause 8.3.1).

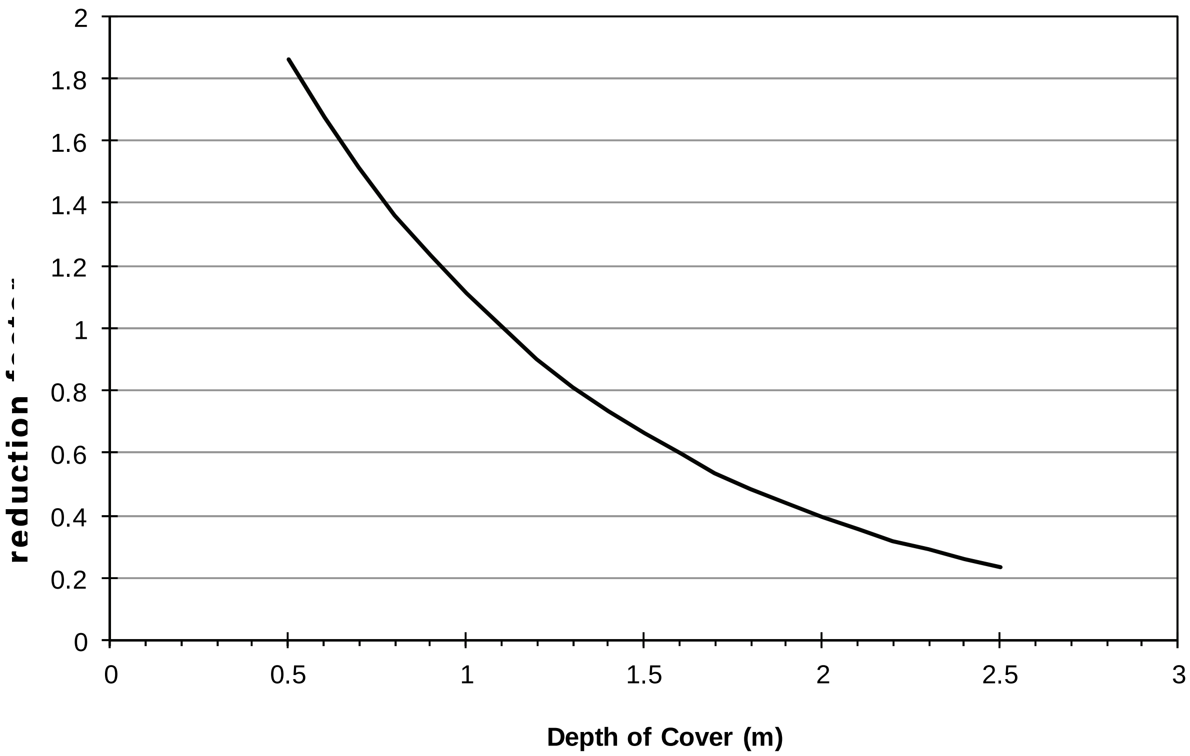


FIGURE 10 - REDUCTION IN EXTERNAL INTERFERENCE TOTAL FAILURE FREQUENCY DUE TO DEPTH OF COVER

Figure 11 shows a simple reduction factor for a surveillance interval which can be used to assess the reduction in damage incidence rate in the estimation of the failure frequency due to external interference. This reduction factor has been derived from the results of studies carried out by UKOPA relating infringement incidence data to damage incidence data (see A2.3 Ref 27). The relationship is normalised to a default fortnightly interval (typically an aerial survey) and allows the effect of increasing or decreasing the surveillance interval to be taken into account provided that the surveillance technique is the same. If the method of surveillance also changes (e.g. walking or driving surveys instead of aerial surveys), then consideration should also be given to factors including activity detection rates and the likelihood of successful intervention before pipeline damage occurs.

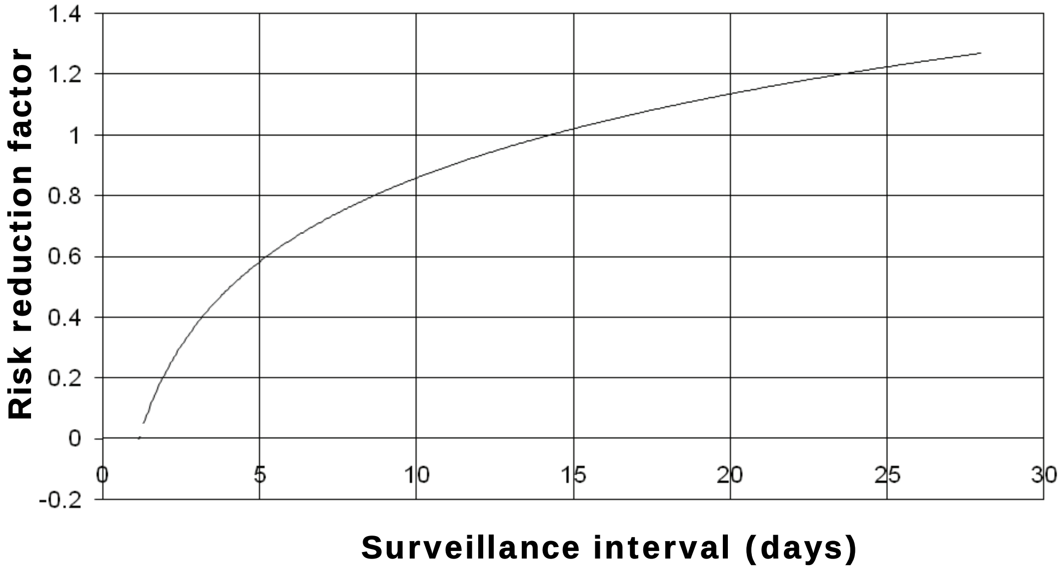


FIGURE 11 - REDUCTION IN EXTERNAL INTERFERENCE TOTAL FAILURE FREQUENCY DUE TO SURVEILLANCE FREQUENCY

Table 1 gives reduction factor which applies to pipeline protection measures which can be used to determine the reduction in damage incidence rate in the estimation of failure frequency due to external interference (see A2.3 Ref 28). The factor in Table 1 is a best estimate value for the purposes of ALARP calculations for concrete slabs designed in line with IGEM/TD/1 Edition 5 (see Section 8.1.4). When undertaking an ALARP calculation it is conservative to over-estimate the effectiveness of the risk reduction measure under consideration. It may therefore be appropriate to assume a higher factor than the factor in Table 1 if the analyst wants to take a more cautious approach when undertaking the ALARP calculation.

MEASURE	RISK REDUCTION FACTOR
Installation of concrete (or equivalent) slab protection	0.1

Note 1: The installation of visible warning tapes identifying that the slab is protecting a high pressure gas pipeline is considered to be good practice. Alternatively the visible indication of the presence of a high pressure gas pipeline can be incorporated into the design of the slab.

Note 2: The physical barrier mitigation measures should apply to the whole pipeline interaction length to justify the values.

Note 3: The above risk reduction factor is recommended for pipeline operators to apply when assessing whether the risks have been made 'as low as reasonably practicable' (ALARP). The equivalent factors that are applied by the HSE when assessing the acceptability of proposed new developments in the vicinity of high pressure gas pipelines are summarised in Appendix 3.

TABLE 2 - RISK REDUCTION FACTORS FOR ADDITIONAL MEASURES

8.2.5 Reduction factors given in Figures 8 and 9 affect the pipeline tolerance to defects and therefore the probability of failure (PoF), whereas the reduction factors given in Figures 10 and 11 and for concrete slabbing in Table 2 affect the damage incident rate (I/OE).

For site-specific risk assessments, the main factors affecting failure frequency should be given careful consideration, and the appropriate reduction factors should be calculated and applied as follows:

a) probability of failure, PoF, determined using the recommended reduction factors given in this section for:
   - R_{df} (reduction factor for design factor) and
   - R_{wt} (factor for wall thickness).

   Note: R_{df} and R_{wt} have been derived from a parameter study in which R_{df} is derived for a constant wall thickness of 5 mm, and R_{wt} is derived for a constant design factor of 0.72. These reduction factors can be applied together within the limits of applicability given in Table 1, when used in conjunction with the base pipeline failure frequencies given in Appendix 4.

b) the factor reduction on number of incidents (or incident rate), determined using the recommended reduction factors given in this section for:
   - R_{dc} (reduction factor for depth of cover);
   - R_p (reduction factor for protection (slabbing and marking)).

8.2.6 Factors for risk control measures along the pipeline route to reduce the number of incidents may be applied as follows for other mitigation measures, using reduction factors assessed by the risk analyst for specific situations:

- R_s (reduction factor for surveillance frequency)
- R_{lv} (reduction factor for additional liaison visits)
- R_{mp} (reduction factor for additional high visibility marker posts).

With respect to land use planning developments in the vicinity of pipelines, the application of R_s and R_{lv} are not usually applied but might be appropriate for controlling risks in specific circumstances, for example short term/temporary developments such as fairs, festivals, temporary construction sites etc.

8.3 IMPLEMENTATION OF RISK MITIGATION MEASURES

The implementation or use of risk mitigation measures for damage mechanisms identified as applying to a specific site should be formally documented. The

implementation of risk mitigation measures relating to external interference is considered in this section. In some cases, the risk mitigation for external interference may reduce the likelihood of failure due to other damage mechanisms, for example, increased wall thickness will also reduce the likelihood of failure due to corrosion and material and construction defects (see Appendix 4).

8.3.1 The implementation of risk mitigation measures should be carried out in accordance with IGEM/TD/1 and the requirements of this section:

- re-laying the pipeline in increased wall thickness

  The pipeline wall thickness should be determined in accordance with IGEM/TD/1 Edition 5 Section 6, constructed in accordance with Section 7 and tested in accordance with Section 8. Particular care is required where the consolidation of the pipeline trench bed is disturbed allowing settlement. Settlement at the tie in points with the existing pipeline should be avoided. The function and integrity of pipeline corrosion protection across the new section and at the points of connection with the existing pipeline should be confirmed to be adequate and fit for purpose in accordance with Section 12 of IGEM/TD/1 Edition 5.

  The rationale for the design of the new pipeline section should be specified and justified in relation to the need for risk reduction, for example:
  - design factor specified as 0.3 to reduce pipeline PoF at operating conditions
  - selection of the wall thickness to achieve an acceptable pipeline PoF
  - selection of wall thickness in relation to risks in new planned development
  - selection of design factor and wall thickness based on ALARP calculations (see Appendix 5).

- laying slabbing over the pipeline

  Installation of slabbing to provide impact protection to the pipeline should be carried out in accordance with the UKOPA specification for pipeline protection (A2.3 ref 28, see also Section 8.1.4). Consideration should be given to the structural loads imposed on the pipeline by the slabbing. The installation of concrete slabbing over the pipeline may restrict access to the pipeline in the event of coating deterioration or corrosion damage. Therefore, it is recommended that a coating survey (DCVG or Pearson) is carried out prior to the installation of slabbing, the results of previous in-line inspections are assessed to determine whether there are any indications of corrosion in the length of pipeline to be slabbed which may need assessment and/or repair prior to slabbing, and the functionality and integrity of the CP system is confirmed before and after installation of the slabbing.

- taking account of increased depth of cover

  Increased depth of cover at the location under consideration may be taken into account where this exceeds the code requirements specified in Sub-Section 7.16 of IGEM/TD/1 Edition 5. A full survey of the actual depth of cover over the full interaction distance at the location under consideration should be carried out in order to record the depth of cover. A justification of the permanence of the depth of cover should be prepared, including the reason for the increased depth of cover, the type of soil, the susceptibility to landslides and the current and future land use. The depth of cover should be rechecked at specified locations during all future pipeline audits carried out in accordance with clause 12.4.2 of IGEM/TD/1 Edition 5 to affirm the pipeline MOP.

Note: Increasing the depth of cover by lowering the pipeline trench or bunding the pipeline is not recommended.

- installing additional pipeline markers

  Sub-Section 7.26 of IGEM/TD/1 Edition 5 states that pipeline markers should be installed at field boundaries, at all crossings and, where practicable, at changes in pipeline direction. Installation of high visibility pipeline markers in addition to these requirements, which provide further information on contacts and emergency telephone numbers, may be applied as a risk mitigation measure.

- increasing surveillance frequency

  Clause 12.6.2 of IGEM/TD/1 Edition 5 states that aerial surveillance should be carried out at two weekly intervals. Increasing the surveillance frequency will increase the likelihood of detection of activities which may damage the pipeline. The surveillance interval may, therefore, be reduced using walking or vantage point surveys at specific locations as a risk mitigation measure.

Full details of any additional mitigation measures installed or implemented should be recorded in the pipeline records systems and included in the MAPD for the pipeline.

APPENDIX 1 : GLOSSARY, ACRONYMS, ABBREVIATIONS, SYMBOLS, UNITS AND SUBSCRIPTS

A1.1 GLOSSARY

dangerous dose	Specified dose which results in: “severe distress to almost everyone; a substantial fraction (of people exposed to it) requiring medical attention; some people (exposed to it) are seriously injured requiring prolonged treatment; any highly-susceptible people (exposed to it) might be killed.” *Note: Normally taken as 1000 thermal dose units (kW $m^{-2})^{4/3}$ s)*
event tree	Provides a systematic way of identifying all of the possible outcomes from a hazardous event. *Note: In this case, the initial event for a pipeline would be the release itself. The tree is then used to identify the likelihood of leak/rupture, ignition, the possible types of release, etc.*
failure cause	Reason for a pipeline reaching a “limit state”. *Note: Examples are external interference, external corrosion and growth of defects due to fatigue.*
proximity distance	Minimum distance permissible between the pipeline and any normally occupied building or traffic route. *Note: For this standard, as derived from Figures 6 and 7 of IGEM/TD/1 Edition 5.*
societal risk	Relationship between the frequency and number of people in a given population suffering a specified level of harm from the realisation of specific hazards.
steady state	Final state which a pipeline system attains when the effects of external disturbances have ceased.

All other definitions are given in IGEM/G/4 which is freely available by downloading a printable version from IGEM’s website, www.igem.org.uk.

Recommended and legacy gas metering arrangements are given in IGEM/G/1 which is freely available by downloading a printable version from IGEM’s website, www.igem.org.uk.

A1.2 ACRONYMS AND ABBREVIATIONS

AC	Alternating current
ALARP	As low as reasonably practicable
BPD	Building proximity distance
CP	Cathodic protection
DC	Direct current
dia	Diameter
FFREQ	Failure frequency
GB	Great Britain
HSE	Health and Safety Executive
IGEM	Institution of Gas Engineers and Managers
LPA	Local Planning Authority
LUP	Land use planning
MAHP	Major accident hazard pipeline
MAPD	Major Accident Prevention Document
MOP	Maximum operating pressure
PADHI	Planning Advice for Developments Near Hazardous Installations

PRI	Pressure regulating installation
PSR	Pipelines Safety Regulations
OE	Operational exposure
QRA	Quantified risk assessment
SCC	Stress corrosion cracking
TS	Tensile strength
TFF	Total failure frequency
SMYS	Specified minimum yield strength
UKOPA	United Kingdom Onshore Pipeline Operators' Association
UK	United Kingdom
W/T	Wall thickness.

A1.3 SYMBOLS

d	pipeline diameter
D,R	dimensions pertaining to interaction and thermal radiation hazard distances
F	pipeline failure frequency
I	number of incidents of external interference events causing damage and failure
N	number of
OE	operational exposure
P	Probability
PoF	pipeline probability of failure
p	pipeline operating pressure
R	reduction factor
t	time
te	tonne
W	intensity of thermal radiation (flux).

A1.4 UNITS

bar	bar
J	Joules
km	kilometres
km yr	kilometre year
kW m^{-2}	kilowatts per square metre
m	metres
mm	millimetres
m s^{-1}	metres per second
s	seconds
tdu	thermal dose unit.

A1.5 SUBSCRIPTS

dc	depth of cover
df	design factor
ign	ignition
lv	liaison visits
mp	high visibility marker posts
p	protection
r	rate
s	surveillance frequency
wt	wall thickness.

APPENDIX 2 : REFERENCES

This Standard is set out against a background of legislation in force in GB at the time of publication. Similar considerations are likely to apply in other countries where reference to appropriate national legislation is necessary. The following list is not exhaustive.

All relevant legislation must be complied with and relevant Approved Codes of Practice (ACoPs), official Guidance Notes and referenced codes, standards, etc. shall be taken into account.

Where British Standards, etc. are quoted, equivalent national or international standards, etc. equally may be appropriate.

Care shall be taken to ensure that the latest editions of the relevant documents are used.

A2.1 UK LEGISLATION

A2.1.1 Regulations and Orders

- Notification of Installations Handling Hazardous Substances Regulations
- Pipelines Safety Regulations 1996 SI 1996 No 825 (and associated Guidance HSL82)
- Town and Country Planning Act (General Permitted Development) Order 1995 SI 1995 No 48.

A2.2 HSE ACOPS AND GUIDANCE

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APPENDIX 3 : SUMMARY OF HSE METHODOLOGY FOR THE PROVISION OF ADVICE ON PLANNING DEVELOPMENTS IN THE VICINITY OF MAJOR ACCIDENT HAZARD PIPELINES IN THE UK

A3.1 HSE sets Land Use Planning (LUP) Zones for major hazard sites, including high pressure pipelines transporting defined hazardous substances, so that it can provide advice to the LPAs on the risks posed by major hazards to people in the surrounding area and the risks can be given due weight in making planning decisions.

LUP Zones are used by HSE for MAHPs as defined by Regulation 18 and Schedule 2 of the Pipeline Safety Regulations (PSR) and to pipelines that were notified under the Notification of Installations Handling Hazardous Substances Regulations 1982 before the enactment of PSR in 1996.

A3.2 LUP Zones define three areas:

(a) inner zone, which is immediately adjacent to the pipeline

(b) middle zone, which applies to proposed significant development

(c) outer zone which applies to proposed vulnerable or very large populations.

The zone boundaries are determined by HSE using a process for calculating individual risk levels, based on information provided to HSE by the pipeline operator. HSE then notifies the inner, middle and outer zone distances to LPAs. The outer zone distance is also called the “consultation zone” within which the risk implications of planning developments have to be considered by the LPA.

A3.3 LPAs in Great Britain are responsible for land use planning decisions under the Town and Country Planning Act 1990, and HSE is a statutory consultee with responsibility to provide advice with respect to public safety for specified developments planned within, or which straddle, the consultation zone.

Detailed guidance defining the HSE advice (advise against or do not advise against) for various types of development is contained in a comprehensive document issued by HSE website entitled “Planning Advice for Developments near Hazardous Installations” (PADHI).

A3.4 A developer or LPA may wish to seek further information to see whether the risk at the specific development location is different from the generalised LUP-Zone notified by HSE, or whether additional risk reduction measures (risk mitigation) can be applied at that location, to allow the planned development to proceed.

A3.5 LUP Zones notified to LPAs by HSE are based on generic pipeline details provided in the operator’s pipeline notification, and do not cover local variations. Where local pipeline details differ from the notified conditions, including whether the pipeline has additional protection, for example thicker walled pipe or slabbing, near the proposed development, a detailed risk assessment can be carried out by HSE to assess any change to zone boundaries.

With regard to slabbing, HSE apply the risk reduction factors given in Table 3.

Barrier Type	Probability that Barrier Fails
Concrete Slab Only	0.15
Slab and Marker Tapes	0.125

TABLE 3 - PROBABILITY OF BARRIER FAILURE

HSE do not apply risk reduction factors described in Section 8.2.6 in any pipeline risk assessments undertaken for Land Use Planning purposes.

A3.6 At the time when a pipeline operator becomes aware of the possibility of a development near a pipeline, especially if it involves an increase in population within one building proximity distance (BPD), the operator needs to assess the population increase against original routing parameters. In some cases it may decide to initiate a full societal risk assessment to define acceptability or otherwise of the development against the societal risk curve presented in Appendix 3 of IGEM/TD/1 Edition 5.

A3.7 In these cases, there is a need to re-assess the impact of site specific details on the risk levels within the interaction zone using an established risk assessment methodology. The guidance in this Standard is provided for use by pipeline operators, LPAs, developers and any person involved in the risk assessment of developments in the vicinity of existing high pressure gas pipelines. It is based on the established best practice methodology for pipeline risk assessment.

A3.8 It is recommended that the methodology be used for the prediction of site-specific risk levels for consideration as required for the re-assessment of LUP developments, so that specific local conditions can be taken into account. The process is shown in Figure 11. PADHI+ leads to HSE's LUP advice though it is only one factor Planning Authorities consider before they make a planning decision to grant or not to grant planning permission.

HSE has adopted a risk-based approach for calculating the distances to the zone boundaries from the pipeline, defining the levels of risk at each boundary as follows:

(a) boundary between inner and middle zone – based on the greater of:
- an individual risk of (1×10^{-5}) per year of dangerous dose or worse to a hypothetical householder and
- the pipeline BPD;

Note: Because of the low levels of risk, some MAHPs will not have an inner zone based on an individual risk level of 1×10^{-5} per year. However, an inner zone equivalent to the BPD has been applied by the HSE to MAHPs. This distance is calculated in accordance with Sub-Section 6.7 of IGEM/TD/1 Edition 5.

(b) boundary between middle zone and outer zone – an individual risk of (1×10^{-6}) per year of dangerous dose or worse to a hypothetical householder;

(c) boundary between outer zone and no consultation required:
- an individual risk of (0.3×10^{-6}) per year of dangerous dose or worse to a hypothetical householder and

Note 1: In cases where the calculation of risks indicates risk levels are lower than (1×10^{-6}) per year and therefore there is no middle zone, an inner is still set equal to the BPD. Similarly, where risk calculations show levels lower than (0.3×10^{-6}) per year, no outer and no middle zones are set and the inner zone is still made equal to the BPD (IGEM/TD/1 Edition 5, Sub-Section 6.7).

Note 2: The location of very large sensitive developments, for example very large hospitals, schools, and people's homes, is restricted to the outer zone (see also Section 7).

Dangerous dose is defined by HSE as a dose of thermal radiation that would cause:
- severe distress to almost everyone in the area or
  - a substantial fraction of the exposed population requiring medical attention or
  - some people being seriously injured, requiring prolonged treatment or

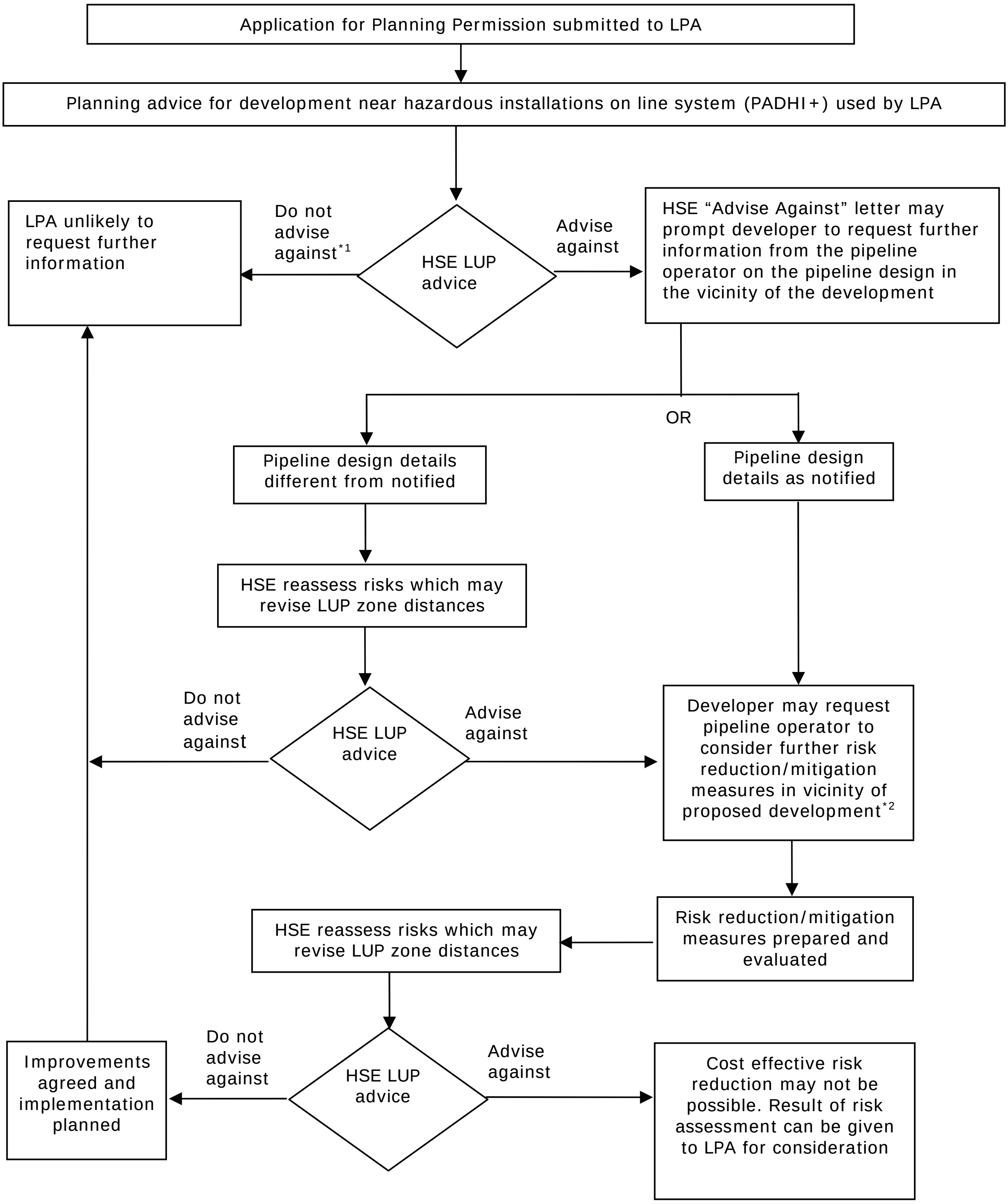
- any highly susceptible/sensitive people being killed.

Note 1: Due to the uncertainties associated with such predictions, the use of the "dangerous dose" concept is used by HSE to define LUP zones. Normally, a "dangerous dose" for thermal radiation is defined as 1000 tdu. These criteria are based on the assumption that the exposed people are typical householders and indoors most of the time and representative of the cross section of the public.

The decision table in PADHI is used with the three (of fewer) zones set by HSE. These zones are routinely based on the details given in the pipeline notification. Where local pipeline details differ from notified details, HSE risk assessors are willing to reconsider a proposed development case using the details relevant to the pipeline near the development.

Note 2: The risk reduction factors given in Sub-Section 8.2 are not currently used in the HSE methodology. Risk reduction factors associated with slabbing are currently under review by HSE.

Note 3: Further information on the above is available from HSE.



*1 *In all cases where the Planning decision is "Do Not Advise Against", the pipeline operator may consider the impact of increased population within the Consultation Zone and the effect on the original routing decisions made for the pipeline, especially if the development is within 1 BPD. If significant population increase is likely to occur if the planning development goes ahead, the pipeline operator may consider carrying out a Societal risk assessment to allow comparison with Societal risk criteria in Appendix 3 of IGEM/TD/1 Edition 5. If unfavourable results are obtained from the Societal risk assessment, the pipeline operator may even consider objecting to the proposed development.*

*2 *Where risk mitigation measures are being considered, the LUP Individual risk assessment and the pipeline operator's Societal risk assessment may be carried out in parallel, so that a common understanding using the same data and risk assessment assumptions allows the effectiveness of the mitigation to be agreed.*

FIGURE 12 - METHODOLOGY FOR THE PREDICTION OF SITE-SPECIFIC RISK LEVELS FOR LUP DEVELOPMENTS

A3.9 SPECIFIC HSE METHODS AND ASSUMPTIONS

Specific methods applied and assumptions made by HSE are given in this Sub-Appendix so that the impact on calculated risk values can be considered.

A3.9.1 Prediction of consequences

In predicting consequences, HSE calculates the reducing release rate with time and so obtains the cumulative amount released. The time required to release the cumulative amount is then compared with the burn time of a fireball containing the cumulative amount released; when the two times are equal, the largest fireball is obtained. The fireball is assumed to have an average surface emissive power of 270 $kW\ m^{-2}$ if the fireball mass is less than 125 te or 200 $kW\ m^{-2}$ if the fireball mass is greater than 125 te. Other modellers may use much higher values for the early stages of the fireball development.

Note: Uncertainties relating to the near field consequence analysis are accommodated through the application of an inner zone based on the BPD.

A3.9.2 Probability of ignition

Typical overall probabilities for Natural Gas, used by HSE, are:

- immediate ignition resulting in a fireball followed by jet fire: 0.25
- delayed ignition resulting in a jet fire: 0.1875
- no ignition: 0.5625

Note: Other probabilities are observed in historical data.

A3.9.3 Thermal radiation and effects

HSE assumes that the typical person will move away from the fire at a speed of 2.5 $m\ s^{-1}$ and will find shelter at a distance of 75 m in an R area or at a distance of 50 m in an S area, provided the thermal radiation dose they receive does not exceed 1,000 tdu. If the cumulative thermal dose exceeds 1,000 tdu, the typical person is deemed to have received a dangerous dose.

The methodology used by HSE calculates the distance to the spontaneous ignition of wood, and people inside buildings within this distance are assumed to become fatalities. People inside buildings outside the distance to the spontaneous ignition but within the piloted ignition of wood are assumed to survive the fireball, but are then assumed to try to escape from the building and to be subject to the thermal radiation effects from the crater fire. For people inside buildings that are beyond the distance to piloted ignition, the building is assumed to provide full protection. People inside buildings engulfed by pool fires or spray fires are assumed not to escape. Other models assume thermal radiation levels equivalent to the piloted ignition of wood for escape from buildings.

HSE assumes that the average householder is present 100% of the time. The proportion of time the average householder spends indoors during the day is 90%, and the proportion at night is 99%.

For further details of HSE's consequence models, (see A2.3 Refs 12, 13 and 15 to 18).

APPENDIX 4 : FAILURE FREQUENCIES FOR UK PIPELINES

In deriving the failure frequency for a specific pipeline, all credible damage mechanisms and location specific factors that can influence the frequency of failure due to each individual mechanism need to be assessed.

A4.1 ALL DAMAGE MECHANISMS

Pipeline failure frequencies for UK pipelines are derived from data published by UKOPA. Guidance provided in this Appendix is based on the 8th Report of the UKOPA Fault Database Management Group, Pipeline Product Loss Incidents 1962 - 2010 (see A2.3 Ref 5). Updates are available on the UKOPA website.

Failure frequencies are presented in this Appendix in failures per 1000 km yr for the following holes sizes:

- Pin hole - Equivalent hole diameter up to 6 mm
- Small hole - Equivalent hole diameter greater than 6 mm to 40 mm
- Large hole - Equivalent hole diameter greater than 40 mm but less than pipe diameter
- Rupture - Equivalent hole diameter equal to or greater than pipe diameter

In deriving pipeline failure frequencies induced by specific damage mechanisms for use in pipeline risk assessment, account needs to be taken of pipeline-specific factors such as wall thickness, pressure, diameter, material properties, location, environment and pipeline operator management practices.

The recommendations given in A4.2 to A4.7 for failure frequency for the different damage mechanisms apply to UK MAHPs.

A4.2 PREDICTION OF PIPELINE FAILURE FREQUENCY DUE TO EXTERNAL INTERFERENCE

Pipeline damage due to external (third party) interference is random in nature, and as operational failure data is sparse, recognized engineering practice requires that a predictive model is used to calculate failure frequencies for specific pipelines. These models allow the prediction of failure frequencies taking into account pipeline diameter, wall thickness, material properties and pressure. A model for predicting the failure frequency due to external interference is described in A2.3 ref 3. A simple methodology developed using this model is given in A4.2.1.

A4.2.1 Generic Pipeline Failure Frequency Curve for External Interference

A generic pipeline frequency curve for external interference, which can be used with the failure frequency reduction factors for design factor and wall thickness given in Figures 7 and 6 respectively, is derived by predicting the failure frequency for pipelines of varying diameter with a constant design factor of 0.72, a constant wall thickness of 5 mm and material grade of X65 i.e. varying pressure. This curve is shown in Figure 13. The generic failure frequency curve has been generated using probabilities of failure produced using the original dent-gouge model (see A2.3 Refs 1 and 3). The failure model is based on a 2-dimensional crack model, and predicts through-wall failure, not whether the failure mode is a leak or a rupture. However, the leak/rupture failure mode is dependent upon the critical length of an axial defect, which is dependent upon both the diameter and the wall thickness. Figure 14 gives the proportion of ruptures which should be applied to the total failure rate obtained from Figure 13.

Note 1: Predicted failure frequencies due to external third party interference increase with material grade due to the consequent reduction in wall thickness, so the generic curve given in Figure 13 can be conservatively applied to pipelines with material grades of X65 and lower.

Note 2: The generic curve given in Figure 13 provides failure frequencies for pipelines in R areas. Failure frequencies for pipelines in S areas may be derived by multiplying the R area failure frequency by a factor of 4, as recommended in clause 8.1.7.

Use of the generic failure frequency curve is conservative. Where risk levels are critical, a pipeline-specific analysis needs to be carried out using an appropriate failure frequency prediction tool (e.g. FFREQ).

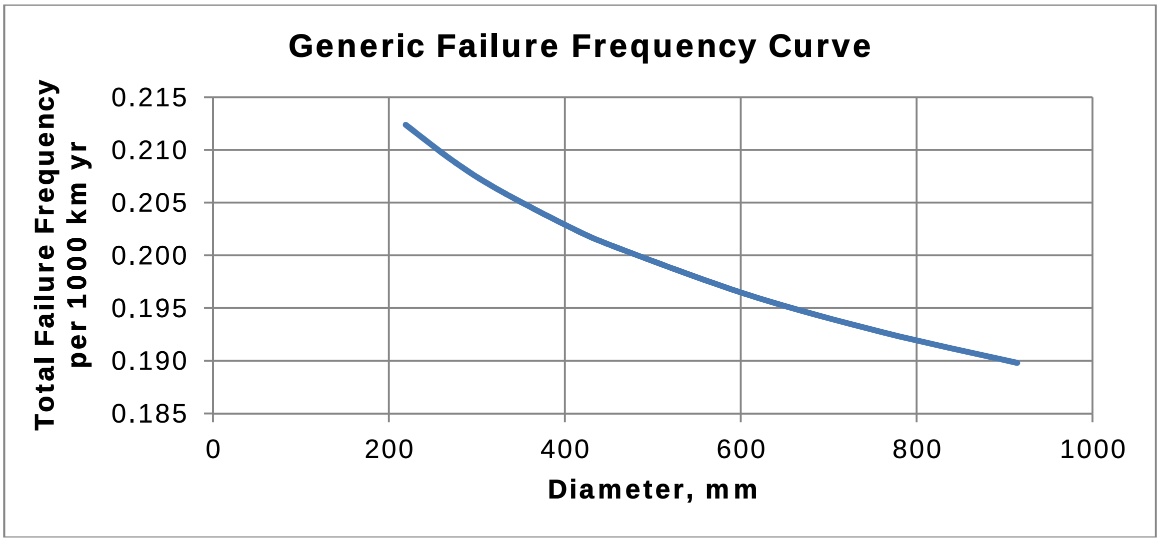


FIGURE 13 - GENERIC FAILURE FREQUENCY CURVE FOR ESTIMATION OF FAILURE FREQUENCY DUE TO EXTERNAL INTERFERENCE

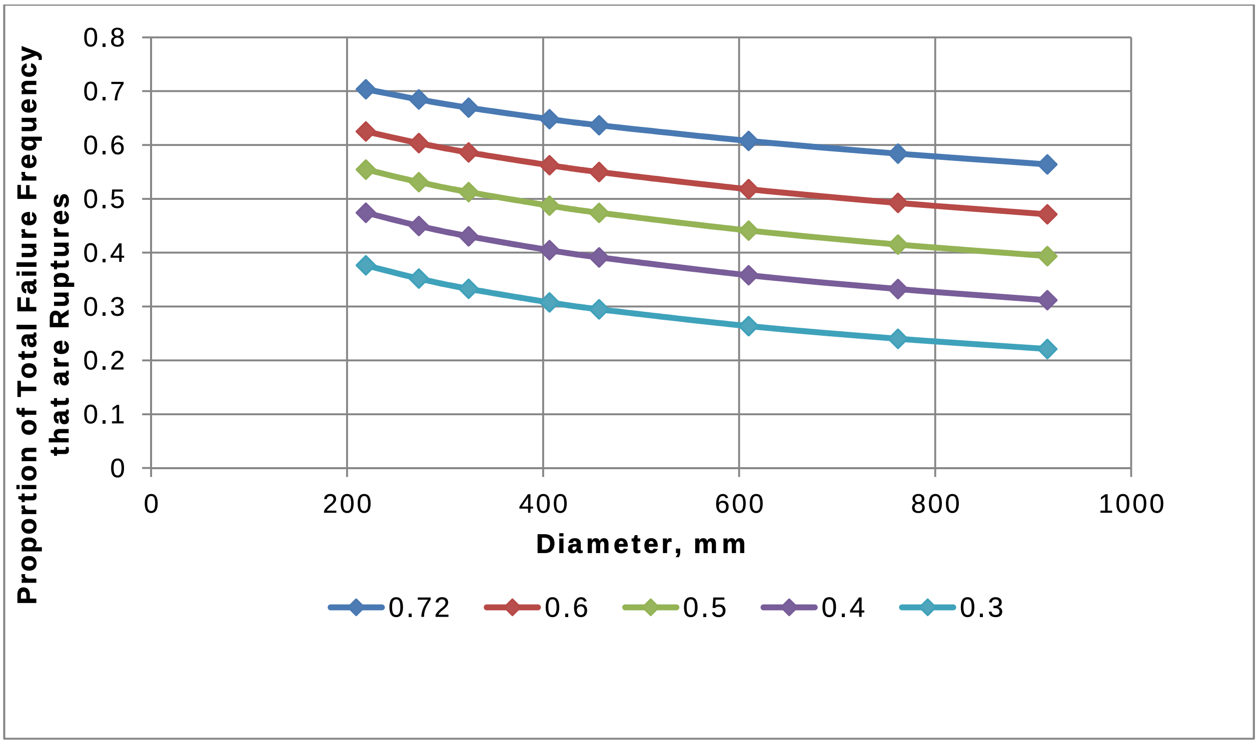


FIGURE 14 - PROPORTION OF RUPTURES TO BE APPLIED TO TOTAL FAILURE RATE DERIVED FROM FIGURE 13

Examples estimating the failure frequency using the generic failure frequency curve, and the design factor and wall thickness failure frequency reduction factors for specific pipeline cases, are given below.

A4.2.2 Estimation of Pipeline External Interference Failure Frequency Using the Generic Failure Frequency Curve

To estimate the external interference failure frequency, the generic failure frequency curve is used together with the appropriate reduction factors for design factor and wall thickness, where:

Total Failure Frequency TFF = GTFF x R_{df} x R_{wt}

The rupture failure frequency, RFF, can then be calculated from the total failure frequency and the proportion of ruptures:

RFF = TFF x RF

PARAMETERS		EXAMPLE			SOURCE
		1	2	3	
Outside Diameter (mm)	OD	219.1	609.6	914.4	
Wall Thickness (mm)	t	6.3	9.52	11.91	
Design Factor	f	0.3	0.5	0.72	
Reduction factor for design factor	R_{df}	0.67	0.81	1.00	Figure 7
Reduction factor for wall thickness	R_{wt}	0.60	0.28	0.19	Figure 8
Generic Total Failure Frequency (per 1000 km years)	GTFF	0.212	0.196	0.190	Figure 13
Proportion of Ruptures	RF	0.377	0.441	0.564	Figure 14
Total Failure Frequency (per 1000 km years)	**TFF**	**0.082**	**0.044**	**0.036**	per 1000 km yr
Rupture Failure Frequency (per 1000 km years)	**RFF**	**0.031**	**0.020**	**0.020**	per 1000 km yr

TABLE 4 - EXAMPLES - CALCULATION OF PIPELINE FAILURE FREQUENCY DUE TO EXTERNAL INTERFERENCE

A4.2.3 Pipeline External Interference Failure Frequency Predictions for Specific Pipe Cases

The use of a generic failure frequency curve for external interference described in A4.2.1 and A4.2.2 allows conservative failure frequency estimates for specific pipeline cases to be readily estimated. However, the approach is approximate and, where possible, predictions for the specific pipe case under consideration need to be carried out using a recognised failure frequency prediction model.

A4.2.4 **Critical Defect Size**

Damage caused by external interference typically includes gouges, which are of a narrow, slot shape, and are modelled as crack-like defects. For high-pressure gas releases (in which the energy of the depressurizing gas does not decay immediately), the critical size of a crack-like defect at which the failure mode changes from leak to rupture, i.e. when the critical length is exceeded, needs to be considered. The maximum area through which the high pressure gas escapes at the critical length is usually determined as an equivalent hole size in order to calculate the maximum leak release rate.

Typical values of the equivalent hole diameter for critical defect lengths required to calculate release rates for pipelines operating at a design factor of 0.72 are given in Table 5.

DIAMETER (mm)	WALL THICKNESS (mm)	MATERIAL GRADE	CRITICAL DEFECT LENGTH (mm)	CRITICAL HOLE DIAMETER LIMIT RUPTURE/LEAK (mm)
168.3	6.35	X42	30.92	2.42
219.1	6.35	X46	33.79	2.98
273	6.35	X52	35.21	3.42
323.9	6.35	X52	38.33	4.05
406.4	7.9	X52	47.92	5.09
508	7.9	X52	53.53	6.35
609	9.52	X60	63.55	7.50
762	9.52	X60	71.13	9.39
914	11.9	X65	82.38	10.56

TABLE 5 - CRITICAL DEFECT LENGTHS AND EQUIVALENT HOLE DIAMETERS FOR UKOPA PIPELINE CASES OPERATING AT A DESIGN FACTOR R_{df} = 0.72

A4.3 PIPELINE FAILURE FREQUENCY DUE TO EXTERNAL CORROSION

A4.3.1 **External corrosion**

UKOPA data for external corrosion is given in Table 6. The failure frequency due to corrosion in the UK is dependent upon the year of construction and hence the age and applicable coating, corrosion protection design standards and corrosion control procedures. Corrosion control procedures include:

- monitored and controlled CP, and
- regular in-line inspection, and
- defect assessment and remedial action.

The data shows that to date there is no operational experience of rupture failure due to corrosion in the UK.

WALL THICKNESS (mm)	PIN	SMALL HOLE	LARGE HOLE	RUPTURE	TOTAL
< 5	0.304	0.076	negligible	negligible	0.38
> 5 ≤ 10	0.032	0.011	0.003	negligible	0.046
> 10 ≤ 15	negligible	negligible	negligible	negligible	negligible
> 15	negligible	negligible	negligible	negligible	negligible

Note 1: Units in failures per 1000 km yr.

Note 2: Negligible means that the failure rate would be dominated by the other failure modes identified in the Table above and hence, for the purposes of the risk assessment, a value of zero can be assumed.

TABLE 6 - FAILURE FREQUENCY DUE TO EXTERNAL CORROSION vs WALL THICKNESS

For pipelines commissioned pre-1980, it is recommended that the corrosion failure frequencies in Table 5 be applied unless corrosion control procedures have been applied. For pipelines of wall thickness up to 15 mm commissioned after 1980 and with corrosion control procedures applied, the corrosion failure frequency rate can be assumed to reduce by a factor of 10. For pipelines of any age with wall thicknesses greater than 15 mm and with corrosion control procedures in place, the corrosion failure frequency can be assumed to be negligible (based on an analysis of UKOPA pipeline fault data carried out A2.3 Ref 21).

A4.3.2 Internal corrosion

Review of UKOPA data confirms that the incidence of internal corrosion in MAHPs in the UK to date is low. The likelihood of occurrence of internal corrosion is negligible for pipelines which transport sweet dry Natural Gas.

A4.4 PIPELINE FAILURE FREQUENCY DUE TO MATERIAL AND CONSTRUCTION DEFECTS

UKOPA data for the failure frequency due to material and construction defects is given in Table 7; this shows that the failure frequency reduces as the wall thickness increases. The UKOPA data indicates that material and construction failures occur as leaks, and that no ruptures have been recorded to date.

WALL THICKNESS (mm)	PIN	SMALL HOLE	LARGE HOLE	RUPTURE	TOTAL
< 5	0.418	0.019	negligible	negligible	0.437
> 5 ≤ 10	0.040	0.016	negligible	negligible	0.056
>10 ≤ 15	0.017	0.000	negligible	negligible	0.017
> 15	negligible	0.017	negligible	negligible	0.017

Note: Negligible means that the failure rate would be dominated by the other failure modes identified in the Table above and hence, for the purposes of the risk assessment, a value of zero can be assumed.

TABLE 7 - FAILURE FREQUENCY DUE TO MATERIAL AND CONSTRUCTION DEFECTS vs WALL THICKNESS

Failure frequency due to material and construction defects in the UK is dependent upon the year of construction and hence the age, design and construction standards, in particular the material selection controls and welding inspection standards applied which have improved significantly since the early 1970s. For pipelines commissioned after 1980, the material and construction failure frequency rate can be assumed to reduce by a factor of 5 (based on an analysis of UKOPA pipeline fault data carried out A2.3 Ref 21).

A4.5 PIPELINE FAILURE FREQUENCY DUE TO GROUND MOVEMENT

There is insufficient historical data to establish a relationship between ground movement failure data and individual pipeline parameters.

The failure frequency of a specific pipeline due to ground movement is dependent upon the susceptibility to natural landsliding along the route, and this needs to be assessed on location specific basis.

A4.5.1 Natural landslides

Based on a detailed assessment of pipeline failure frequency due to natural landsliding in the UK, UKOPA has concluded that the predicted background failure rate of 2.14×10^{-4} per 1000 km yr due to large holes and ruptures caused by natural landslides is applicable to all UK MAHPs. Based on evidence from European pipeline incidents caused by ground movement, failures as ruptures or large holes due to ground movement are assumed to be equally likely.

However, where a site specific assessment has been carried out to determine the local susceptibility to land sliding and the associated likelihood of slope instability, the failure rates due to ground movement caused by natural landsliding can be obtained from Table 8.

Note: Where site specific assessment confirms that slope instability is likely or may occur, particular consideration should be given to thin wall pipelines which may be vulnerable in the event of ground movement.

Description	Large Hole	Ruptures
Slope instability is negligible or unlikely to occur but may be affected by slope movement on adjacent areas	$0 \leq 4.5 \times 10^{-5}$	$0 \leq 4.5 \times 10^{-5}$
Slope instability may have occurred in the past or may occur in the future	$4.5 \times 10^{-5} \leq 1.1 \times 10^{-4}$	$4.5 \times 10^{-5} \leq 1.1 \times 10^{-4}$
Slope instability is likely and site specific assessment is required	$1.1 \times 10^{-4} \leq 5.0 \times 10^{-4}$	$1.1 \times 10^{-4} \leq 5.0 \times 10^{-4}$

TABLE 8 - PIPELINE FAILURE FREQUENCIES PER 1000 KM YR DUE TO NATURAL LANDSLIDING

A4.5.2 Man made ground movement

Table 8 above provides suggested failure frequencies for natural landslides, i.e. slippages of land that is a part of a naturally formed geological formation. There is an additional risk of a landsliding occurring from artificial (man made) earth mounds. The construction of these types of made up land in the vicinity of a pipeline would normally be controlled and managed through the pipeline operator's third party activity notification and work supervision processes. Any development work of this type that takes place that is not notified to the pipeline operator should then be identified though pipeline surveillance. The operator would ensure that any made up land is designed and controlled to minimise the impact of land slippage affecting the pipeline. Mining and quarrying activities would also be controlled and managed by the pipeline operator to limit the potential for them to impact upon the integrity of the pipeline.

If, at the location of the development under consideration, there is an existing man made earth structure, for example spoil from mining activities, then its potential impact on the pipeline should be taken into account when undertaking the pipeline risk assessment. Where this is the case and it is not practical to carry out a detailed assessment, then the value in Table 6 for 'slope instability is likely and site specific assessment required' should be used.

A4.6 PIPELINE FAILURE FREQUENCY DUE TO OTHER CAUSES

Pipeline failure rates due to causes other than those defined in A4.1 to A4.5 need to be assessed on a pipeline specific basis. Relevant causes may include overpressure, fatigue etc., and will vary according to the operating regime and/or location of the pipeline or pipeline section.

The UKOPA product loss data indicates that other causes account for a failure rate of 0.063 (leaks only) per 1000 km yr. The UKOPA pipeline fault data report (A2.3 Ref 4) confirms that 62.5% of the incidents recorded in this category relate to pre-1970 pipelines, and are not relevant to pipelines designed, constructed and operated in accordance with current pipeline standards. Based on this, a failure rate due to other causes of 0.023 leaks per 1000 km yr is recommended.

APPENDIX 5 : EXAMPLES OF SITE-SPECIFIC RISK CALCULATIONS

Background

A Planning Application for a new housing development consisting of 78 houses in a rural area has been lodged with the LPA. On checking the records, the LPA find that located in close proximity to the proposed development is a high pressure gas pipeline, which has LUP zones. A schematic diagram of the site, pipeline and associated LUP zones is shown in Figure 15.

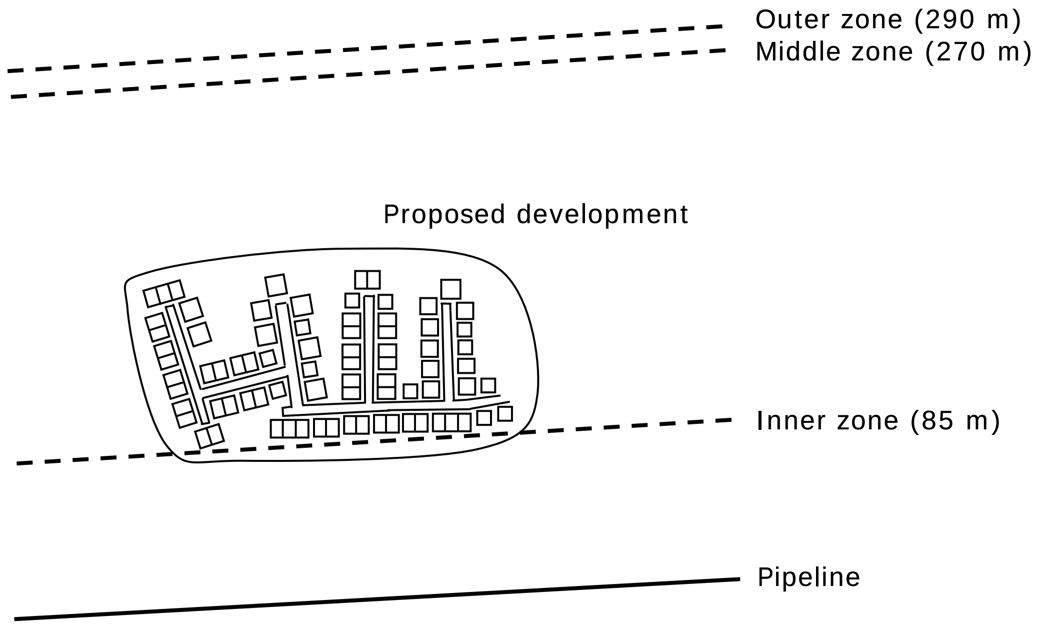


FIGURE 15 - PROPOSED DEVELOPMENT EXAMPLE

The closest house is approximately 86 m from the pipeline. The LPA checks the LUP zones against advice from the HSE, and discovers that for a larger development of more than 30 dwelling units, if more than 10% of the development is in the middle zone, the HSE advice is against allowing the development to proceed. Therefore, the LPA informs the developer that it will refuse planning permission on safety grounds.

The developer contacts the pipeline operator to see if there are any special conditions associated with the pipeline which could affect the planning application. After discussion with the developer, the operator confirms that the pipeline design conditions are as notified to HSE and, therefore, the only possibility is to perform a full risk assessment to quantify the risks associated with the operation of the pipeline and, if the risks are not considered tolerable, to consider possible mitigation measures in order to reduce the risk at the proposed development.

Risk assessment

The developer commissions a QRA of the pipeline at the location of the proposed development. The aim is to quantify the risk associated with siting the development in close proximity to the pipeline and to assess possible mitigation measures that could be applied.

The pipeline parameters are:

- pipeline diameter - 914.4 mm
- wall thickness - 12.7 mm
- steel grade - X60
- MOP - 75 bar
- depth of cover - 1.1 m
- area classification - rural (Type ‘R’ Area)

The BPD is calculated to be 80.25 m in Type ‘R’ areas.

Consequence analysis

For societal risk, the consequences of pipeline rupture only have been assessed; calculations performed for ignited punctures on this pipeline have shown that none of the houses lie within the hazard range for punctures and therefore they are not considered further in the societal risk analysis.

It is assumed that in the event of failure, the pressure would be maintained at the upstream end of the pipeline and blocked downstream, with no backflow. It is further assumed that the rupture occurs midway along the pipeline and the event is modelled as a two-ended, full-bore “balanced flow” release, with no pipeline misalignment.

It has been assumed that ignited ruptures will ignite immediately 50% of the time and will be delayed by 30 seconds for the remaining 50% of the time. For the pipeline in this case study, the total ignition probability in the event of rupture has been calculated to be 0.8, giving probabilities of both immediate and delayed ignition of 0.4.

The 1800 tdu casualty criterion was used in the assessment, with an assumed escape speed of 2.5 $m\ s^{-1}$.

The results from the consequence analysis are:

- building burning distance - 226 m (based on piloted ignition of wood)
- escape distance - 345 m.

For the section of pipeline where all the development would be inside the “building burning distance” in the event of a rupture, the analysis assumes that no safe shelter is available. For the remaining section of pipeline within the interaction distance, the shelter density has been taken to be equivalent to the density of houses in the half of the development that is furthest away from the pipeline, i.e. approximately 40 shelters per hectare.

Failure frequency

The pipeline failure frequency data due to third party damage has been calculated using the model FFREQ with the following additional assumptions:

- 2/3 Charpy Energy - 27 J (FFREQ default)
- Seam type - LSAW.

The third party damage rupture frequency in Type ‘R’ areas is calculated to be (4.82×10^{-3}) per 1000 km yr.

A background ground movement rupture frequency has also been included of (2.1×10^{-4}) per 1000 km yr.

The total rupture frequency is, therefore, (5.03×10^{-3}) per 1000 km yr.

Risk analysis

Individual Risk has been calculated at the location of the nearest house (86 m) for a person who is present all the time and outdoors for 10% of the time and was found to be 9.1×10^{-7} per year. The individual risk reduces from this value with increasing distance from the pipeline. On this basis, the assessment has focussed on societal risk and this is discussed in more detail below.

For societal risk, an FN curve has been calculated and is shown in Figure 16. The curve crosses the IGEM/TD/1 Edition 5 societal risk criterion line and, therefore, risk mitigation measures are considered.

Mitigation measures

The mitigation measure of installing concrete slab protection plus visible warning is considered for risk reduction.

The effect of this mitigation measure is to reduce the third party damage failure frequency by a factor of 20, i.e. the failure frequency is multiplied by a factor of 0.05.

The revised rupture frequency for the pipeline is, therefore:

Rupture frequency $= (0.05 \times 4.82 \times 10^{-3}) + (2.1 \times 10^{-4})$ per 1000 km yr
$= (4.51 \times 10^{-4})$ per 1000 km yr.

Figure 16 shows the FN curve lies well within the IGEM/TD/1 societal risk criterion envelope and, therefore, the risks would be judged to be tolerable. It has been assumed that the protection is applied to the full interaction length of the pipeline. However, given associated cost data for installing slabbing, a full cost-benefit analysis could be performed to optimise the length of pipeline section that is slabbed with regards to cost and reduction in risk.

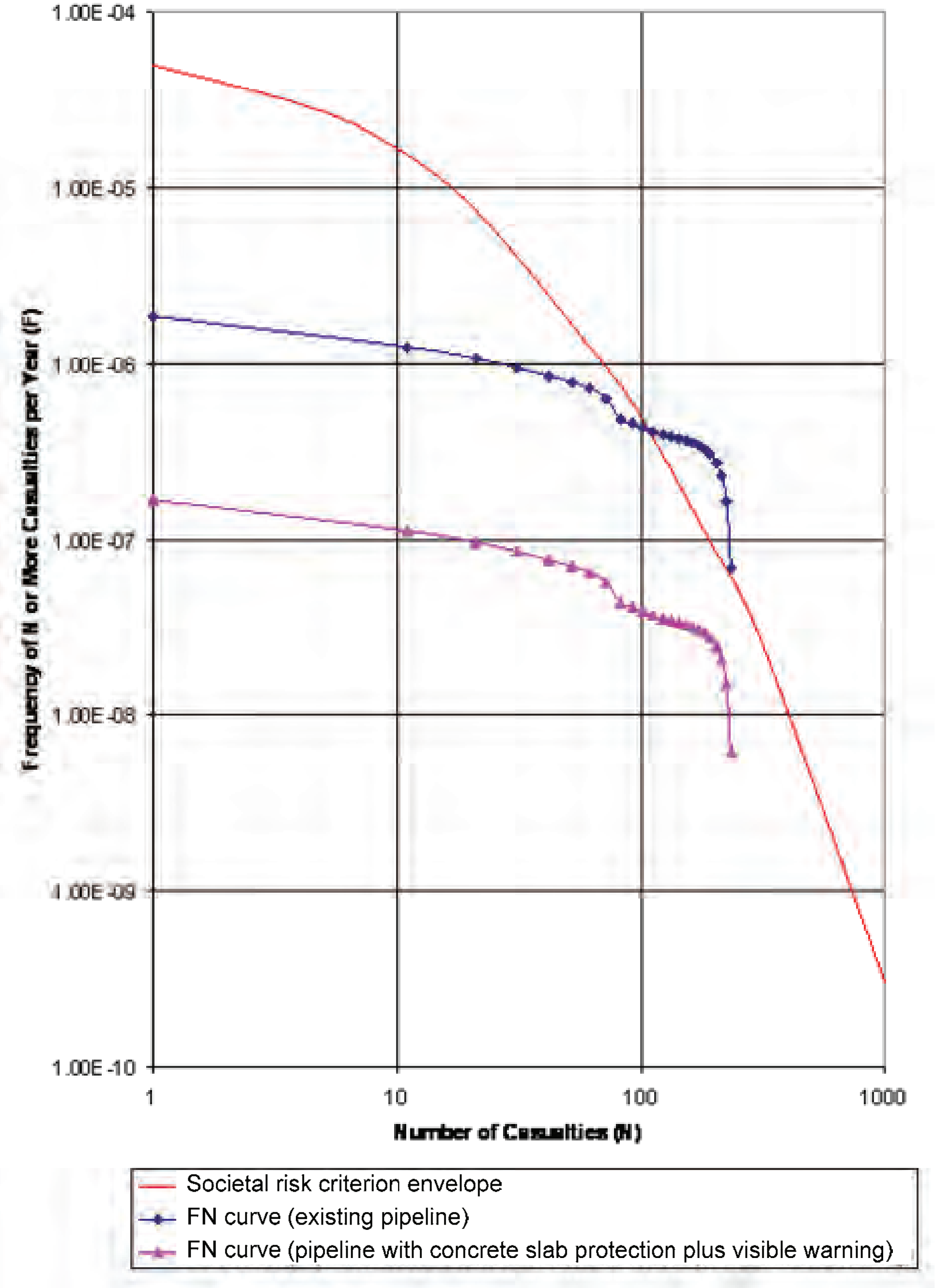


FIGURE 16 - SOCIETAL RISK FN CURVES FOR PROPOSED DEVELOPMENT

APPENDIX 6 : RECOMMENDED BENCHMARK SOLUTIONS FOR GAS PIPELINES

Benchmark data for specific risk assessment parameters are given below for four pipeline cases. It is recommended that the results generated using any risk assessment methodology are compared with at least one of the benchmark cases to demonstrate consistency with the methodology and recommendations included in this supplement, and the quality and accuracy of calculated results.

RISK ASSESSMENT PARAMETERS	BENCHMARK DATA			
	Case 1	Case 2	Case 3	Case 4
Pipeline diameter (mm)	273	508	762	914
Wall thickness (mm)	6.35	7.9	9.52	11.9
Material grade	X52	X52	X60	X65
Pressure (bar)	38	70	38	70
Area classification	S	R	R	R
Depth of cover (m)	1.0	0.9	1.2	1.1
Building Proximity Distance (m)	16.6	49.2	43.5	76.9
Third party damage rupture failure frequency (per 1000 km yr)	0.034	0.039	0.0031	0.0045
Building burning distance for ruptures (m) (based on piloted ignition of wood)	69.5	139.1	155.5	221.0
Escape distance for ruptures (1800 tdu) (m)*	62.0	147.9	176.7	328.8
Escape distance for ruptures (1% lethality) (m)*	83.6	206.5	249.8	452.2

* Assuming a 2.5 m s^{-1} escape speed.

TABLE 9 - BENCHMARK SOLUTIONS

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