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Part 3: Guide to the application of pipeline risk assessment to proposed developments in the vicinity of major hazard pipelines – Supplement to PD 8010-1:2004

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## Introduction

Your comments on this draft are welcome and will assist in the preparation of the consequent British Standard. If no comments are received to the contrary, this draft may be implemented unchanged as a British Standard.

## Submission

The guidance given below is intended to ensure that all comments receive efficient and appropriate attention by the responsible BSI committee. **Annotated drafts are not acceptable and will be rejected.**

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Date: xx/xx/200x	Document: ISO/DIS xxxxx
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1	2	(3)	4	5	(6)	(7)
MB	Clause No./ Subclause No./ Annex (e.g. 3.1)	Paragraph/ Figure/Table/ Note (e.g. Table 1)	Type of comment	Comment (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '... so that the mains connector to which no connection ...	
	6.4	Paragraph 2	its	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	

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**Code of practice for pipelines –**

**Part 3: Guide to the application of pipeline risk assessment to proposed developments in the vicinity of major hazard pipelines – Supplement to PD 8010-1:2004**

**DRAFT FOR PUBLIC COMMENT**

Please note that this is a draft and not a typeset document. Editorial comments are welcomed, but persons commenting on this draft are advised not to comment on detailed matters of typography and layout.

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## Foreword

### Publishing information

This part of PD 8010 was published by BSI and came into effect on **XX Month 200X**. It was prepared by Subcommittee PSE/17/2, *Pipeline transportation systems*, under the authority of Technical Committee PSE/17, *Materials and equipment for petroleum*. A list of organizations represented on this committee can be obtained on request to its secretary.

### Relationship with other publications

PD 8010-3 is a new part of the PD 8010 series, and should be read in conjunction with PD 8010-1. The series comprises:

- Part 1: *Steel pipelines on land*;
- Part 2: *Subsea pipelines*;
- Part 3: *Guide to the application of pipeline risk assessment to proposed developments in the vicinity of major hazard pipelines – Supplement to PD 8010-1:2004*.

### Information about this document

This part of PD 8010 includes worked examples and benchmark solutions that can be used as a basis for specific studies.

### Use of this document

As a code of practice, this part of PD 8010 takes the form of guidance and recommendations. It should not be quoted as if it were a specification and particular care should be taken to ensure that claims of compliance are not misleading.

Any user claiming compliance with this part of PD 8010 is expected to be able to justify any course of action that deviates from its recommendations.

### Presentational conventions

The provisions in this Published Document are presented in roman (i.e. upright) type. Its recommendations are expressed in sentences in which the principal auxiliary verb is “should”.

*Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.*

### Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

### Compliance with a Published Document cannot confer immunity from legal obligations.

Attention is particularly drawn to the Pipelines Safety Regulations 1996 [1].

## Introduction

PD 8010-1:2004, Clause 5 and Annex E provide guidance on the route selection and location of new pipelines in various areas in terms of the acceptable proximity to significant inhabited areas. Clause 5 classifies locations adjacent to pipelines into location classes 1, 2 and 3 according to population density and/or nature of the immediate surrounding area.

The general approach to the risk assessment process follows the stages outlined in PD 8010-1:2004, Annex E. The present part of PD 8010 includes recommendations for:

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

This part of PD 8010 provides guidance for the risk assessment of developments in the vicinity of major hazard pipelines. The guidance is specific to the calculation of risks posed to developments in the vicinity of UK major accident hazard pipelines, but the principles of the risk calculation are generally applicable. The use of such risk assessments to determine the acceptability of developments in accordance with land use planning applied in Great Britain is discussed in Annex A.

The guidance in this part of PD 8010 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 major accident hazard 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.

For significant developments or infringements the 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. Clause 8 describes the application of societal risk, and includes a recommended FN criterion envelope.

## 1 Scope

This part of PD 8010 gives recommendations for the risk assessment of major accident hazard pipelines (MAHPs), guidance on the modelling of failure consequences and determination of failure frequencies for the prediction of individual and societal risks.

The principles of this part of PD 8010 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 recommendations for its use.

This part of PD 8010 is applicable to buried pipelines on land that can be used to carry category D and category E substances that are hazardous by nature of being flammable or liable to cause harm to persons.

## 2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

PD 8010-1:2004, *Code of practice for pipelines – Part 1: Steel pipelines on land*

## 3 Abbreviations

For the purposes of this part of PD 8010, the following abbreviations apply.

ALARP	as low as reasonably practicable
HSE	Health and Safety Executive
MAHP	major accident hazard pipeline
MAOP	maximum allowable operating pressure
MDOB	minimum distance to occupied building
PoF	probability of failure
SMYS	specified minimum yield strength
tdu	thermal dose units
UKOPA	United Kingdom Onshore Pipeline Operators Association
UTS	ultimate tensile strength

## 4 Recommendations for the risk assessment of pipelines

Quantified risk assessment 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.

Pipeline failure frequency is usually expressed in failures per kilometre year or per 1 000 kilometre years. Failure frequency should be predicted using recognized predictive models, or otherwise derived from historical incidents that have occurred in large populations of

existing pipelines, as recorded in recognized, published pipeline data<sup>1)</sup>. Various factors may then be taken into account for the specific pipeline design and operating conditions to obtain the failure rate to be applied.

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 comparison with recognized 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 effect distance (radius) over which people are likely to become casualties. This should take into account people both outdoors and indoors.

Pipelines present a linear risk. 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 Clause 6 and Clause 7).

## **5 Failure of hazardous gas or liquid pipelines**

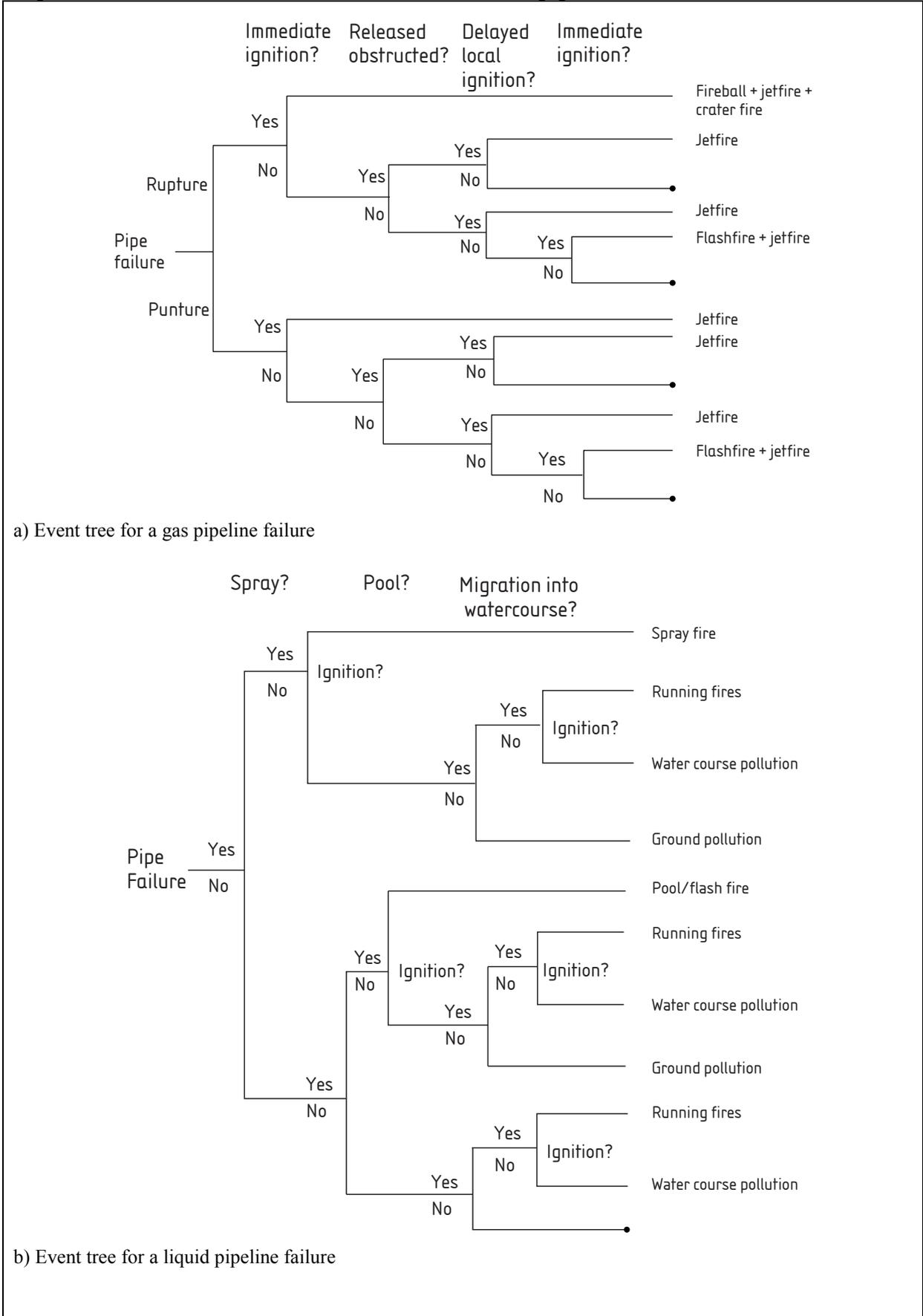
### **5.1 General**

Failure of a hazardous gas or liquid pipeline has the potential to cause 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 consequences of failure are primarily due to the thermal radiation that is produced if the release ignites. This can be caused directly or indirectly, by igniting secondary fires. An event tree for the failure of a hazardous pipeline is shown in Figure 1.

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<sup>1)</sup> CONCAWE Report 3/06 [5], EGIG 05 R.0002 [6] and Advantica Report R8099 [7].

**Figure 1 – Event tree for the failure of a hazardous pipeline**



For a rupture release, it is normally expected that the pipe ends of the failed pipe are aligned and the jets of released fluid interact.

*NOTE 1 For large diameter pipelines (i.e. >300 mm) this is a standard assumption.*

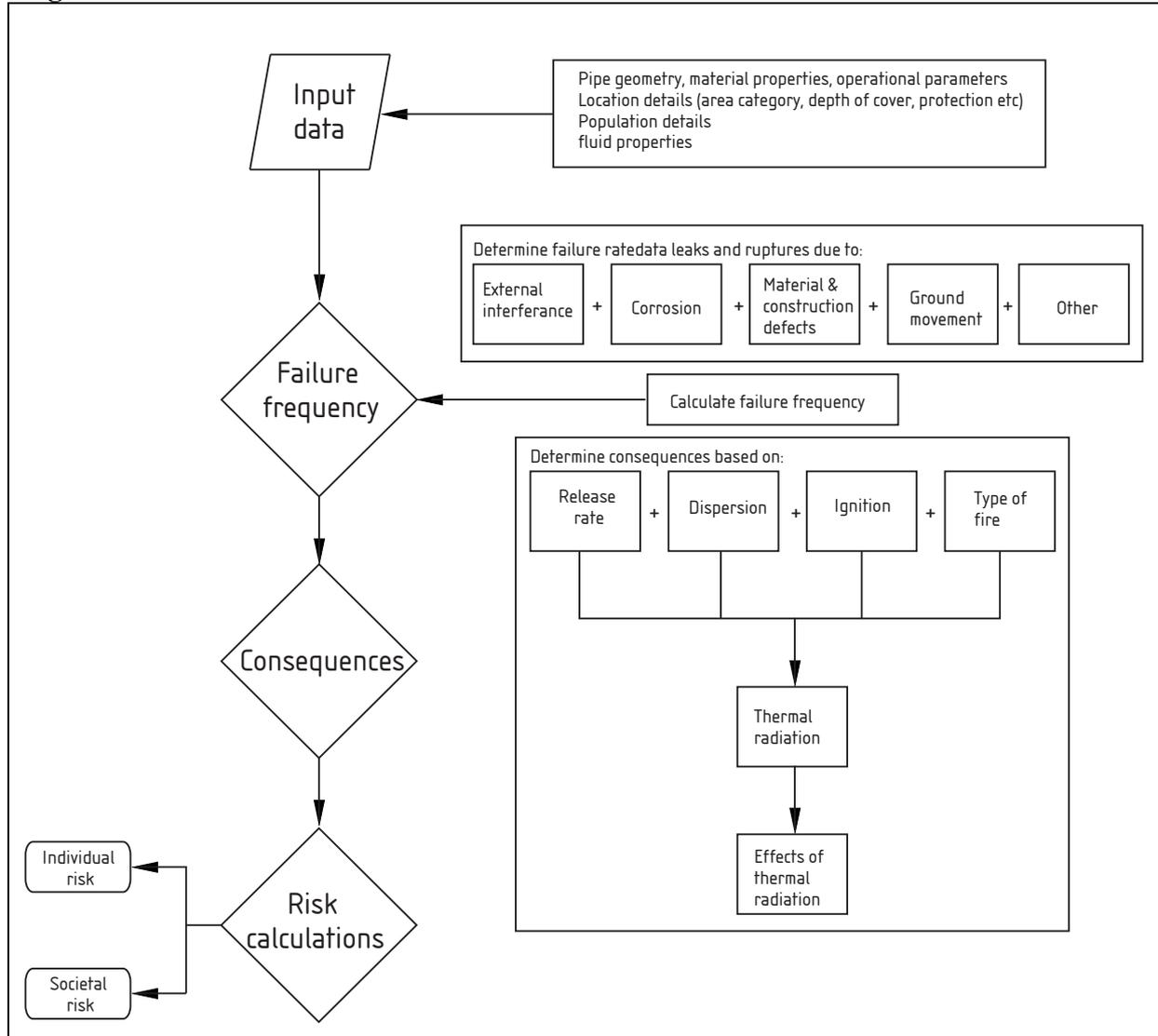
If immediate ignition of a gas release occurs, a fireball can be produced which lasts for up to 30 s and is followed by a crater fire. If ignition is delayed by 30 s or more, it is assumed that a jet (jet unobstructed) or crater (jet obstructed) fire will occur.

For gases or vapour that are heavier than air, or form cold heavier-than-air gas clouds when released, the possibility of flash fires should be taken into account. The extent of such gas clouds depend on prevailing weather conditions at the time of release, and the location of possible sources of ignition.

*NOTE 2 In the case of natural gas, this scenario is not usually considered, as the release has a large momentum flux at the source and this normally has a significant vertical component. The transition to a low momentum (passive) release only occurs when the pipeline has depressurized, at which time the released natural gas is diluted below the lower flammability limit.*

*NOTE 3 Uncertainties relating to the near field consequence analysis are accommodated through the application of an inner zone based on the MDOB, which is calculated using the formula and substance factors given in PD 8010-1:2004, 5.5.3.*

The stages of pipeline risk assessment are represented in Figure 2.

**Figure 2 – Risk calculation flowchart for flammable substances**

In general terms, a quantified risk assessment of a hazardous gas or liquid pipeline consists of four stages:

- a) input of data (pipeline and its location, meteorological conditions, physical properties of the substance, population);
- b) prediction of failure frequency;
- 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.

The primary input data will comprise:

- pipe geometry – outside diameter, wall thickness;
- material properties – e.g. grade (SMYS, TS), toughness (or Charpy impact value) etc.;
- operational parameters – maximum allowable pressure, temperature, pipeline shutdown period;
- location details – length and route of the pipeline to be assessed, location classification (class 1, class 2), depth of cover, additional protection (e.g. concrete slabbing), pipeline marking, development and building categories in the vicinity and their distance from the pipeline, population and occupancy levels, road/rail crossing details, including traffic density, length of pipeline to be assessed;
- product properties – e.g. density and viscosity versus pressure, temperature, calorific value, etc.;
- atmospheric conditions, e.g. ambient temperature, pressure, humidity etc.

## 5.2 Prediction of failure frequency

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 that should be assessed include leaks, i.e. punctures, or line breaks, i.e. ruptures. Leak sizes range from pinholes up to hole sizes that represent critical or unstable defects for particular pipeline parameters. A rupture release is a full bore, double-ended break from which product is released into a crater from both sections of pipe). Typical failure frequencies for UK MAHPs are given in Annex B.

*NOTE 1 In most cases the risk will be dominated by the rupture scenario.*

Leaks should be assessed in terms of a specific range of hole sizes. Failure rate data is usually quoted for the sum of all hole sizes, and should be classified into specific hole sizes to enable the risk assessment to be carried out. To determine the range of hole sizes considered, the hole that which is equivalent to the critical defect size for specific pipeline parameters should be calculated.

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

The failure mode is determined by the critical defect size, i.e. the length of a through-wall defect which becomes unstable at the specific pipeline conditions. This is primarily dependent on the pipe diameter, wall thickness, material properties and the operating pressure. Typical critical hole sizes for high pressure gas pipelines are given in Annex B.

In a risk assessment, the likelihood of each failure scenario is 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 1 000 km per year, which is equivalent to failures per million metres per year.

### 5.3 Prediction of consequences

In the context of pipelines carrying flammable substances, for releases that ignite cause immediate hazards to people and property, consequence models are needed to predict the transient gas or liquid release rate, the ignition probabilities, the characteristics of the resulting fire (i.e. fireball, jet, flash, spray or pool fire), the radiation field produced and the effects of the radiation on people and buildings nearby. The following aspects should be taken into account:

- outflow as a function of time (influenced by failure location and upstream and downstream boundary conditions);
- thermal radiation from the initial and reducing flow into the fireball if the release is ignited immediately;
- thermal radiation from delayed ignition jet and crater fires. Jet fires that are unobstructed can have considerable jet momentum, resulting in a “lift-off” distance before the flame occurs resulting in thermal radiation effects in the far distance, depending on the degree of wind tilt. Crater fires can be modelled as large sheets of flame starting at ground level having thermal radiation effects in the near and middle distance;
- extent of the area covered by a flammable gas cloud causing a possible flash fire downwind of the release, and possible ignition points in downwind areas;
- spillage rate and duration of release from liquid pipeline affecting the local area and possibly causing a spray or pool fire.

Other consequences that are generally found to have a negligible effect on risk compared to fire effects and are difficult to model 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;
- spray fires caused by pressurized liquids;
- pool fires resulting from liquid releases;
- release of flammable liquids into water courses and the potential for running fires;
- pollution of water courses and/or ground due to liquid releases.

The consequence model should also take into account:

- wind speed, because this affects the jet fire tilt and extent of the flash fire and the resulting radiation effects downwind;

*NOTE Weather category, as well as wind speed, also affects gas dispersion of flash fires, and in the UK, the conventional assumption is that night-time weather is modelled as Pasquill Category F2 and daytime is Category D5.*

- wind direction – only needed for a site-specific risk assessment where wind direction will affect the populated area being considered;
- humidity – this affects the proportion of thermal radiation absorbed by the atmosphere;
- the type of ground environment, including topography where appropriate, into which a liquid is released.

There is considerable evidence from actual events and research work that immediate ignition events involving flammable gases can cause a fireball to occur. Typical fireball burn times are 10 s to 30 s depending on pipeline diameter and pressure.

In modelling crater or unobstructed jet 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 the typical assumption made is that the break occurs half-way between a compressor or pump station (or pressure regulating station) and an isolation valve, with pressure being maintained from the compressor or pump station and no reverse flow (with depressurization) occurring at the compression or pump station check valve.

In modelling jet fires from punctures, the release can be considered to be a steady state. The consequence model usually assumes 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, but the conditional probability is reduced.

For non-flashing liquid releases from pipelines, the release rate is often dictated by the pumping rate at the point of release, depending on hole size. Small to medium holes can cause sprays and the hazard distance from spray fires can be significant. Large holes (>50 mm) in high pressure pipelines are likely to release the full pumping rate, so the consequences of large holes are similar to pipeline rupture. The amount released from a liquid pipeline is a function of the time taken to stop pumping, depressurisation of the pipeline, and drain-down of adjacent sections of the pipeline.

#### **5.4 Probability of ignition**

The risks from a pipeline containing a flammable fluid depend critically on whether a release is ignited, and whether ignition occurs immediately or is delayed.

It is usually assumed that immediate ignition occurs within 30 s, and delayed ignition occurs after 30 s. Generic values for ignition probability can be obtained from data from historical incidents and these are product-specific. The various ignition possibilities such as immediate, delayed and obstructed or unobstructed, are drawn out logically on an event tree (see Figure 1) to obtain overall probabilities.

The probability of occurrence of a crater or jet fire is dependent on assumptions made about sources of delayed ignition close to the release point. Typical assumptions result in jet fire probabilities between 0.15 and 0.5.

Flash fires occur when a plume of unignited heavier-than-air gas drifts some distance downwind before finding a source of ignition. The ignition causes the fire to flash back to the source of release and then to cause a jet fire. Flash fires drift further in night-time conditions (category F2) than daytime (category D5). The usual assumption for natural gas is that flash fires do not occur as heavier-than-air plumes are not usually formed following releases of natural gas. The probability of flash fires is considered low, depending on the extent of population in the vicinity of a pipeline. Typical probabilities used are 0.1 during daytime and 0.05 during night-time.

Historical overall probabilities for flammable gases are:

- immediate ignition resulting in a fireball followed by jet fire: 0.2 to 0.25;
- delayed ignition resulting in a jet fire: 0.15 to 0.5;

- delayed ignition resulting in a flash fire followed by a jet fire: 0.05 to 0.1;
- no ignition: 0.2 to 0.5.

Recently published information [2] reports on a review of transmission pipeline incident data which was performed to provide information on the ignition probability for gas releases resulting from pipeline failures.

A linear relationship was demonstrated between the ignition probability and the quantity of gas released expressed in terms of the product of the pipeline pressure ( $p$ ) and the square of the pipeline diameter ( $d^2$ ), which is directly related to the initial gas outflow following a rupture.

Based on this work, the following equations for ignition probability (ratio of the number of ignited incidents to the total number of incidents) are recommended.

a) Ruptures:

$$P_{\text{ign}} = A + Bpd^2$$

where  $P_{\text{ign}}$  is the ignition probability and  $A$  and  $B$  are constants.

This equation is used up to a maximum value of  $P_{\text{ign}}$  of 0.8.

b) Punctures:

$$P_{\text{ign}} = A + Bpd^2/2$$

where  $P_{\text{ign}}$  is the ignition probability and  $A$  and  $B$  are constants.

Natural gas is lighter than air, even at the low temperatures that would apply after a pressurized release, so dispersion of gas into buildings is not expected to occur.

## 5.5 Thermal radiation and effects

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. Thermal radiation is highest at the flame surface and is attenuated with increasing distance 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 that assumes all the energy is emitted from one (or several) point sources within the flame. The energy from the fireball pulse is usually calculated using the view factor method.

Burn data accumulated over many years suggests that the degree of harm produced by thermal radiation is proportional to the product of the exposure period and the intensity raised to a power greater than unity. The index that fits serious burn injury including fatality data is 1.33 or 4/3. Therefore a unit of thermal radiation dose, the thermal dose unit (tdu), is defined as:

$$\text{tdu} = W^{4/3}t$$

where:

$t$  is time, in seconds (s);

$W$  is the intensity of thermal radiation, in kilowatts per square metre (kW/m<sup>2</sup>);

Experimental and other data indicate that thermal radiation dose levels can have differing effects within a on a population depending on individual tolerance to such effects. The variation of effects have been estimated from burn data for human beings which suggests that the radiation level causing a significant likelihood of fatal injury (approximately 25%) in an average population is 1 800 tdu. This level of thermal dose is often used in risk assessments.

*NOTE Various models are available for assessing escape distance inside and outside buildings, and vulnerability. These take into account factors such as escape speed for people outside running away from the fire, location and types of buildings, populations indoors and outdoors, daytime and night-time, etc.*

For fireballs, the thermal radiation effects are calculated using the duration of the fireball to obtain the thermal dose at various distances from the flame surface. A time-weighted method is used to enable the fireball duration to be taken into account. The distance to specific thermal dose levels are obtained, and it is conservative to assess the effects on people outside assuming that no attempt to escape is made. For people inside buildings, the distance to the spontaneous ignitions of wood is calculated, and people inside buildings within this distance are assumed to become casualties. People inside buildings outside the spontaneous ignition range 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. People inside buildings engulfed by pool fires are assumed not to escape.

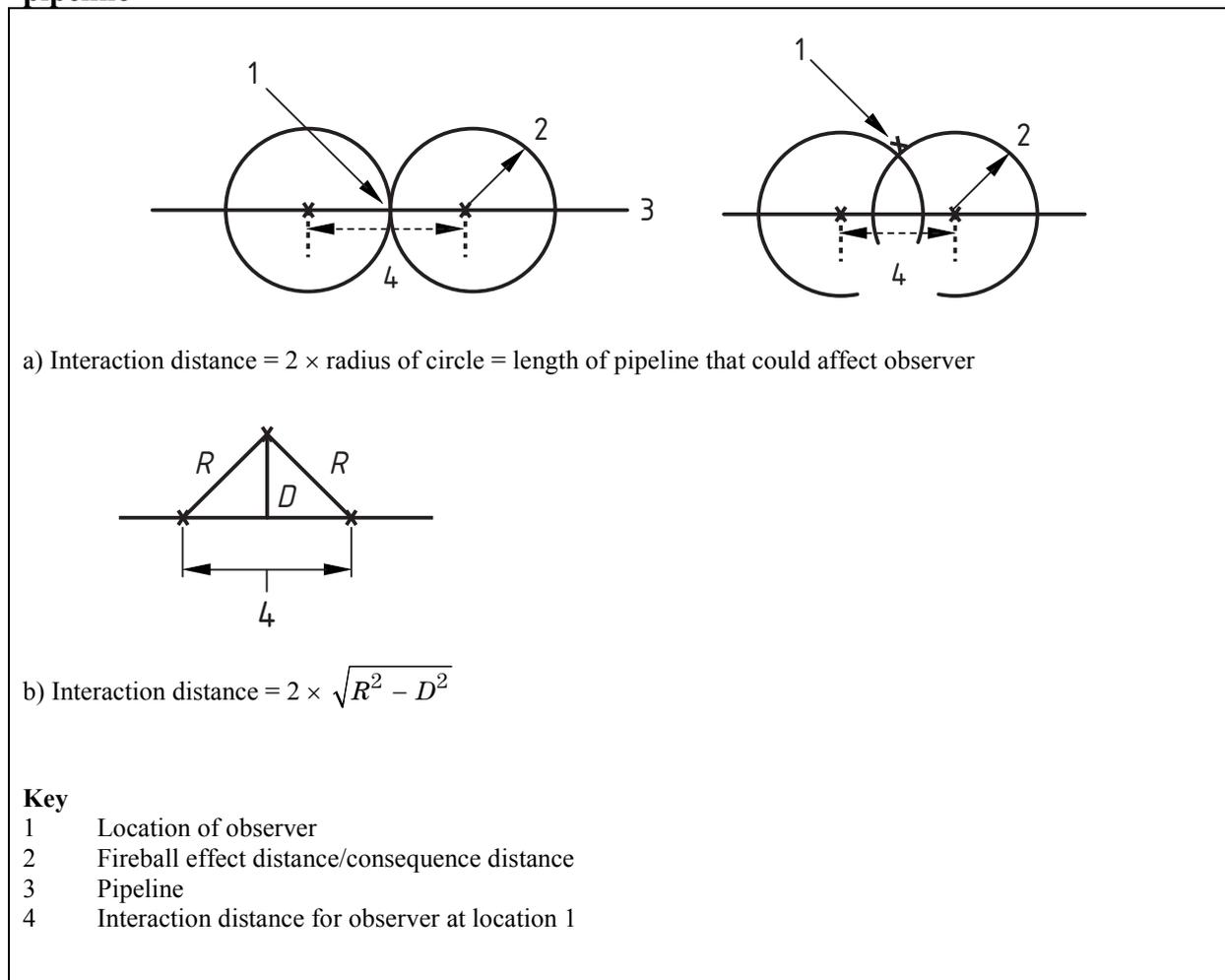
Thermal radiation from crater fires and jet fire effects is generally calculated by assuming that all persons indoors and outdoors try to escape. The cumulative thermal dose is then calculated, and the distance from the fire at which escape is possible without exceeding a threshold dose. A similar approach is adopted for escape from pool fires.

Developments such as schools, hospitals and old peoples' homes are classed as sensitive developments due to the increased vulnerability of the population groups involved to harm from thermal radiation hazards and the increased difficulty in achieving an effective response (e.g. rapid evacuation) to mitigate the consequences. A number of methods may be used to calculate the thermal impact effects of a fire on the adjacent population. Site-specific assessments are needed for industrial premises, workplaces such as call centres, and commercial and leisure developments.

## **6 Calculation of individual risk**

The risks from the various scenarios should be collated and the individual risk profile at various distances is plotted on a graph. From this plot it is possible to identify the risk of a specified effect (e.g. fatality or dangerous dose) to an individual at a given distance from the pipeline. For a simple model where windspeed conditions are zero, the consequences are circular, and the interaction distance is calculated as shown in Figure 3. The interaction distance shown can be multiplied by the pipeline failure frequency, the probability of ignition and the probability of effect to obtain the risk at any distance from the point of release. Shown in cross-section perpendicular to the pipeline, the risk levels are known as the risk transect.

**Figure 3 – Calculation of pipeline length affecting an individual in the vicinity of a pipeline**



## 7 Definition of the extent of the risk assessment for developments in the vicinity of the pipeline

### 7.1 General

The risk assessment applies to acute safety hazards only affecting the immediate health of people who are near the pipeline when an accident occurs.

In the application of risk assessment to assess a development in the vicinity of a pipeline, the physical aspects relating to a pipeline failure specific to the location in question (e.g. shelter density, local geography) should be assessed in detail, and the justification for the assumptions to be applied should be documented.

### 7.2 Pipeline failure frequency

Worldwide databases show that external interference and ground movement dominate pipeline rupture rates, and these have the most effect on risk from pipelines. In most cases it might be relevant to assume that the failure rates due to other damage mechanisms are managed and controlled by the pipeline operator through testing, inspection and maintenance. The failure rate for external interference is influenced by the pipeline wall thickness and design factor, as well as the location class, the pipeline depth of cover and the local installation of pipeline protection such as slabbing. The failure rate for natural ground

movement depends upon the susceptibility to landsliding at the specific location. In some cases other causes might need to be considered in specific locations, such as the quality of girth welds, the potential for stress corrosion cracking (SCC) or alternating current (AC) corrosion and ground subsidence.

The failure frequency associated with each damage mechanism should be determined using recognized published operational data sources<sup>2)</sup>, or predictive models validated using such data. Typical failure frequencies for UK MAHPs based on UKOPA data are given in Annex B.

In determining the external interference failure frequency, account should be taken of the location class, i.e. 1 (population density less than 2.5 persons per hectare) or 2 (population density equal to or greater than 2.5 persons per hectare). It is recommended that the damage incidence rate for location class 2 areas should be assumed to be higher than for class 1 areas. Typically, the factor applied is approximately four times that for location class 1 areas. Data relating to class 1 and 2 incident rates for UK MAHPs is provided by UKOPA [7].

The risk analysis requires the primary input data described in 6.1. Any site-specific variations should be assessed, and justifications for any additional assumptions to be applied locally should be documented. In the case of 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.

The determination of failure rate data requires several complex parameters to be considered, including:

- pipeline diameter;
- pipewall thickness;
- design factor – depends on MAOP;
- depth of cover;
- steel type and properties;
- location class (1 or 2).

The failure rates obtained from database records or predictive models should be justified for application to a site-specific case. Generic failure data might not be applicable to specific cases.

### **7.3 Risk reduction factors for use in site-specific risk assessments**

*NOTE 1 An example of a site-specific risk assessments are given in Annex C. Examples of typical benchmark solutions are given in Annex A.*

Risk mitigation measures are 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:

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<sup>2)</sup> CONCAWE Report 3/06 [5], EGIG 05 R.0002 [6] and Advantica Report R8099 [7].

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

Procedural measures include:

- additional surveillance;
- additional liaison visits.

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.

The pipeline failure frequency due to external interference is obtained as follows:

$$F = \text{PoF} \times I / \text{OE}$$

where:

$F$  is the pipeline failure frequency ;

$I$  is the number of incidents of external interference;

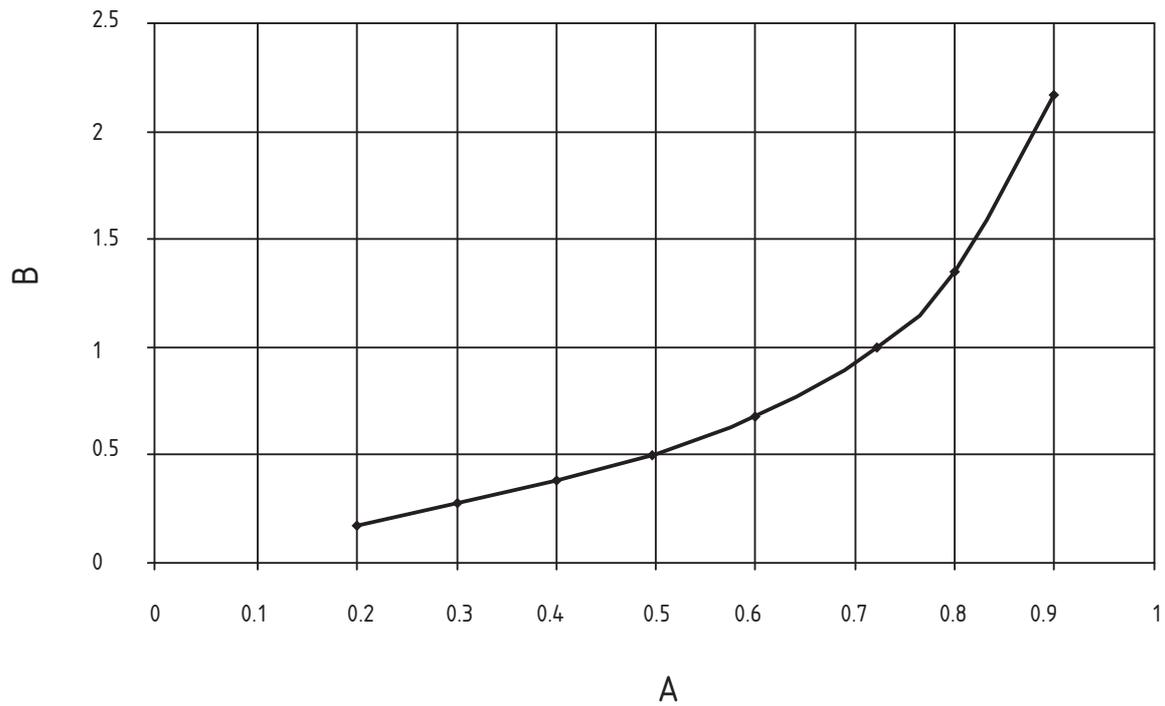
$\text{OE}$  is the operational exposure, in kilometre years (km·y).

*NOTE 2 Pipeline failure frequencies derived from published operational data sources are given in Annex B.*

When predicting site-specific pipeline failure frequencies for external interference, the parameters listed in 7.2 should be taken into account. The influence of specific parameters on the predicted pipeline failure frequencies is given as reduction factors as follows :

- design factor, given in Figure 4;
- wall thickness, given in Figure 5;
- depth of cover, given in Figure 6;
- surveillance frequency, given in Figure 7;
- protection measures, given in Table 1.

**Figure 4 – Reduction in external interference failure frequency due to design factor**

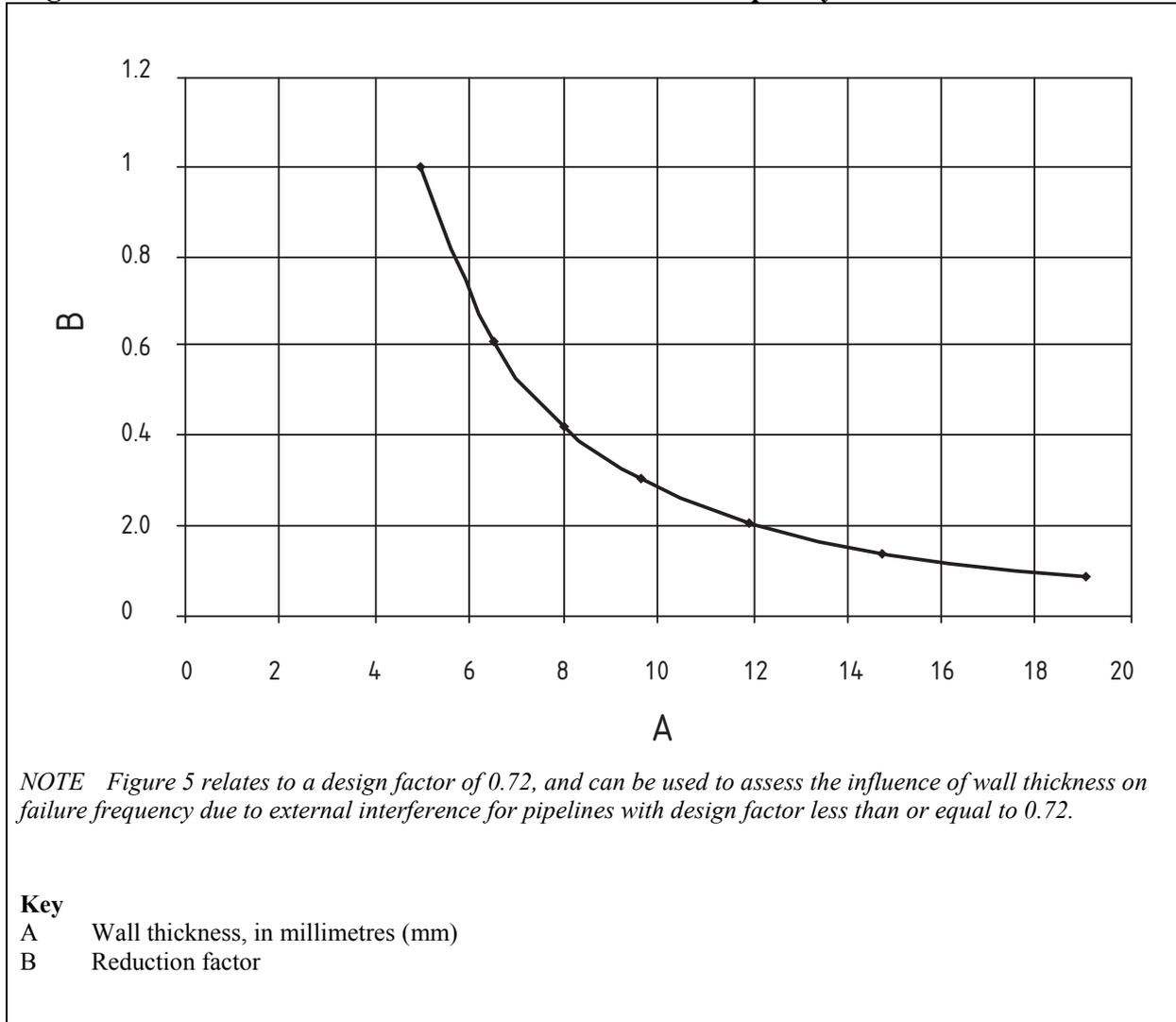


*NOTE* Figure 4 relates to a pipe wall thickness of 5 mm, and can be used to assess the influence of design factor on failure frequencies due to external interference for pipelines with wall thickness equal to or greater than 5 mm.

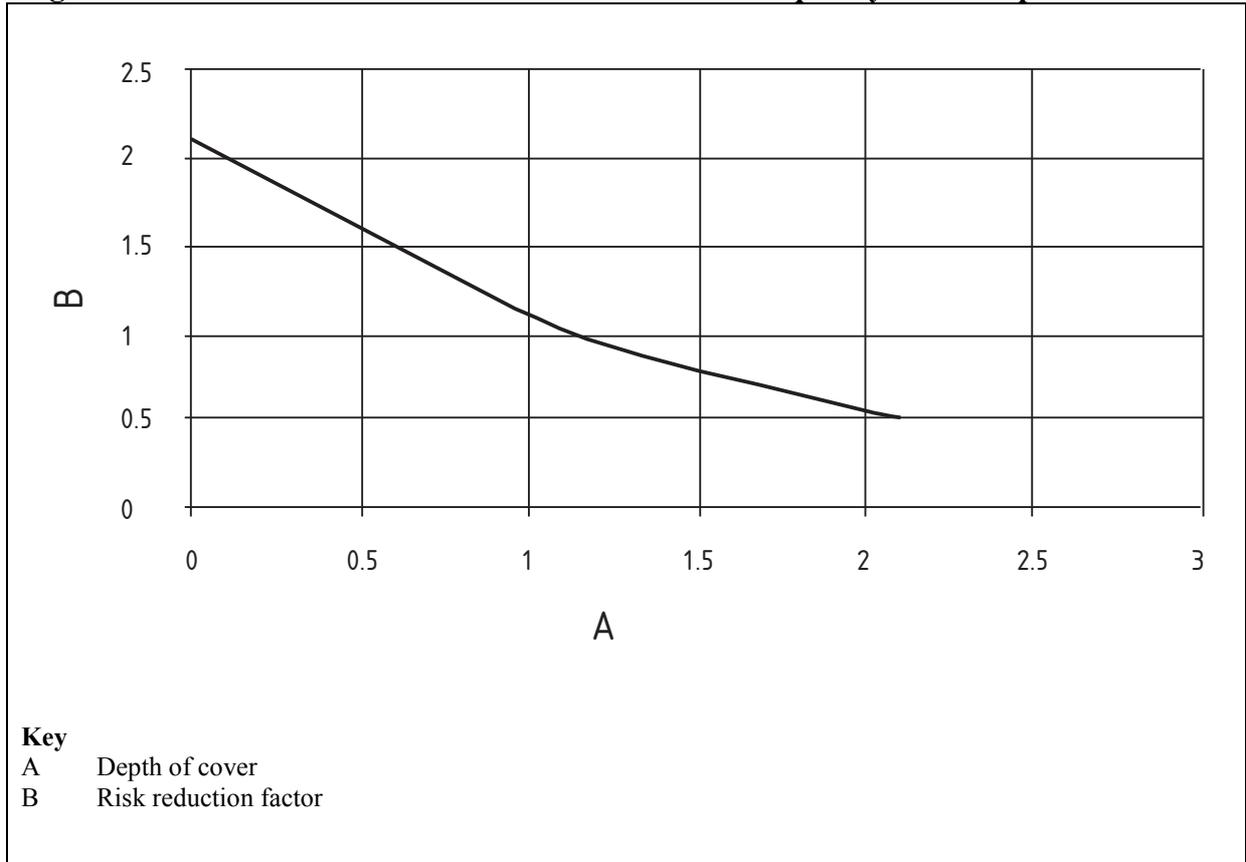
**Key**

- A Design factor
- B Reduction factor

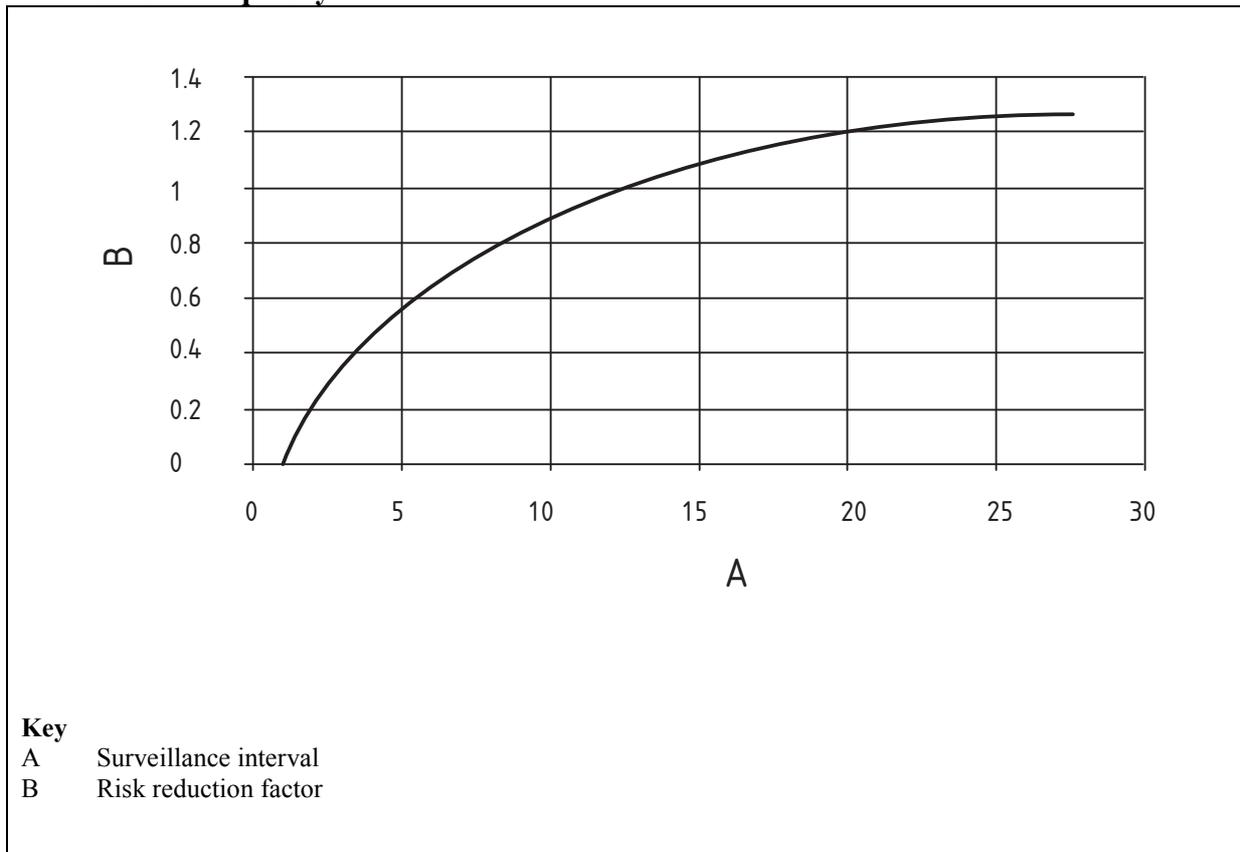
**Figure 5 – Reduction in external interference failure frequency due to wall thickness**



**Figure 6 – Reduction in external interference failure frequency due to depth of cover**



**Figure 7 – Indicative reduction in external interference failure frequency due to surveillance frequency**



**Table 1 – Failure frequency reduction factors for pipeline protection**

Measure	Reduction factor
Installation of concrete slab protection	0.16
Installation of concrete slab protection plus visible warning	0.05

*NOTE 1 Concrete slabbing with high visibility marker tapes has been shown to achieve significant risk reduction factors in excess of 0.1.*

*NOTE 2 In order to use the reduction factor, the physical barrier mitigation measures should apply to the whole pipeline interaction length.*

Reduction factors given in Figure 4 and Figure 5 affect the pipeline tolerance to defects and therefore the PoF, whereas the reduction factors given in Figure 6, Figure 7 and Table 1 affect the damage incident rate, *I*.

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

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

- b) the factor reduction on number of incidents (or incident rate),  $R_{IR}$ , determined using the recommended reduction factors given in this subclause for:
- $R_{dc}$  (reduction factor for depth of cover);
  - $R_p$  [reduction factor for protection (slabbing and marking)];
  - $R_m$  (reduction factor for additional high visibility markers).

A factor for risk control measures along the pipeline route to reduce the number of incidents may be applied using the recommended reduction factors given in this subclause for:

- $R_{lv}$  (reduction factor for additional liaison visits);
- $R_s$  (reduction factor for surveillance frequency).

*NOTE 2 With respect to control of risk to developments in the vicinity of pipelines, the application of  $R_s$ ,  $R_{lv}$  might only be applicable for short term/temporary developments only (e.g. fairs, festivals, temporary construction sites etc).*

## 7.4 Implementation of risk mitigation measures

### 7.4.1 Relaying the pipeline in increased wall thickness

The pipeline should be designed in accordance with PD 8010-1:2004, Clauses **5**, **6** and **8**, constructed in accordance with PD 8010-1:2004, Clause **10**, and tested in accordance with PD 8010-1:2004, Clause **11**. 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 PD 8010-1:2004, Clause **9**.

*NOTE The rationale for the design of the new pipeline section should be specified and justified in relation to the need for risk reduction, i.e.:*

- *design factor specified as 0.3 to minimize pipeline PoF at operating conditions;*
- *selection of the wall thickness to achieve an acceptable pipeline PoF;*
- *selection of wall thickness in relation to risks to new planned development;*
- *selection of design factor and wall thickness based on ALARP calculations.*

### 7.4.2 Laying slabbing over the pipeline

Installation of slabbing to provide impact protection to the pipeline should be carried out in accordance with PD 8010-1:2004, **6.9.7**, in accordance with details specified in IGE/TD/1 Edition 4. Consideration should be given to the structural loads imposed on the pipeline by the slabbing. The installation of concrete slabbing over the pipeline can restrict access to the pipeline in the event of coating deterioration or corrosion damage. It is therefore recommended that a coating survey is carried out prior to the installation of slabbing, that the results of previous in-line inspection are assessed to determine whether there are any indications of corrosion in the length of pipeline to be slabbed that might need assessment and/or repair prior to slabbing, and that the functionality and integrity of the CP system is confirmed before and after installation of the slabbing.

### 7.4.3 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 recommendations given in PD 8010-1:2004, **6.8.3**. 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 land sliding and the current and future land use. The depth of cover should be rechecked at specified locations during pipeline route inspections carried out in accordance with PD 8010-1:2004, **13.3.2** to detect factors that could affect the safety and operation of the pipeline. Such checks should be carried out at intervals not exceeding 4 years.

### 7.4.4 Installing additional pipeline markers

PD 8010-1:2004, **10.14** recommends that pipeline markers should be installed at field boundaries, at all crossings, and where practicable, at changes in pipeline direction. In addition, high visibility pipeline markers, providing further information on contacts and emergency telephone numbers, can be installed as an additional risk mitigation measure. (See PD 8010-1:2004, **13.3.2** and **E.9**.)

### 7.4.5 Increasing surveillance frequency

PD 8010-1:2004, **13.3.2** recommends that pipeline route inspections should be carried out. Where route inspections are carried out at two-weekly intervals, increasing the surveillance frequency will increase the likelihood of detection of activities that could damage the pipeline. The surveillance frequency may be increased 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 or included in the major accident prevention document for the pipeline.

## 8 Societal risk assessment

Societal risk is a measure of the risk due to the frequency of accidents that can cause varying numbers of casualties. The hazards associated with pipelines tend to be high consequence low frequency events, and therefore it is more appropriate that societal risk is used to assess the acceptability of pipeline risk. It is calculated by assessing the frequency and consequences of all of the various accident scenarios which could occur along a length of pipeline. It is of particular significance to pipeline operators because the location of pipelines might be close to populated areas and the impact of multiple fatality accidents on people and society in general.

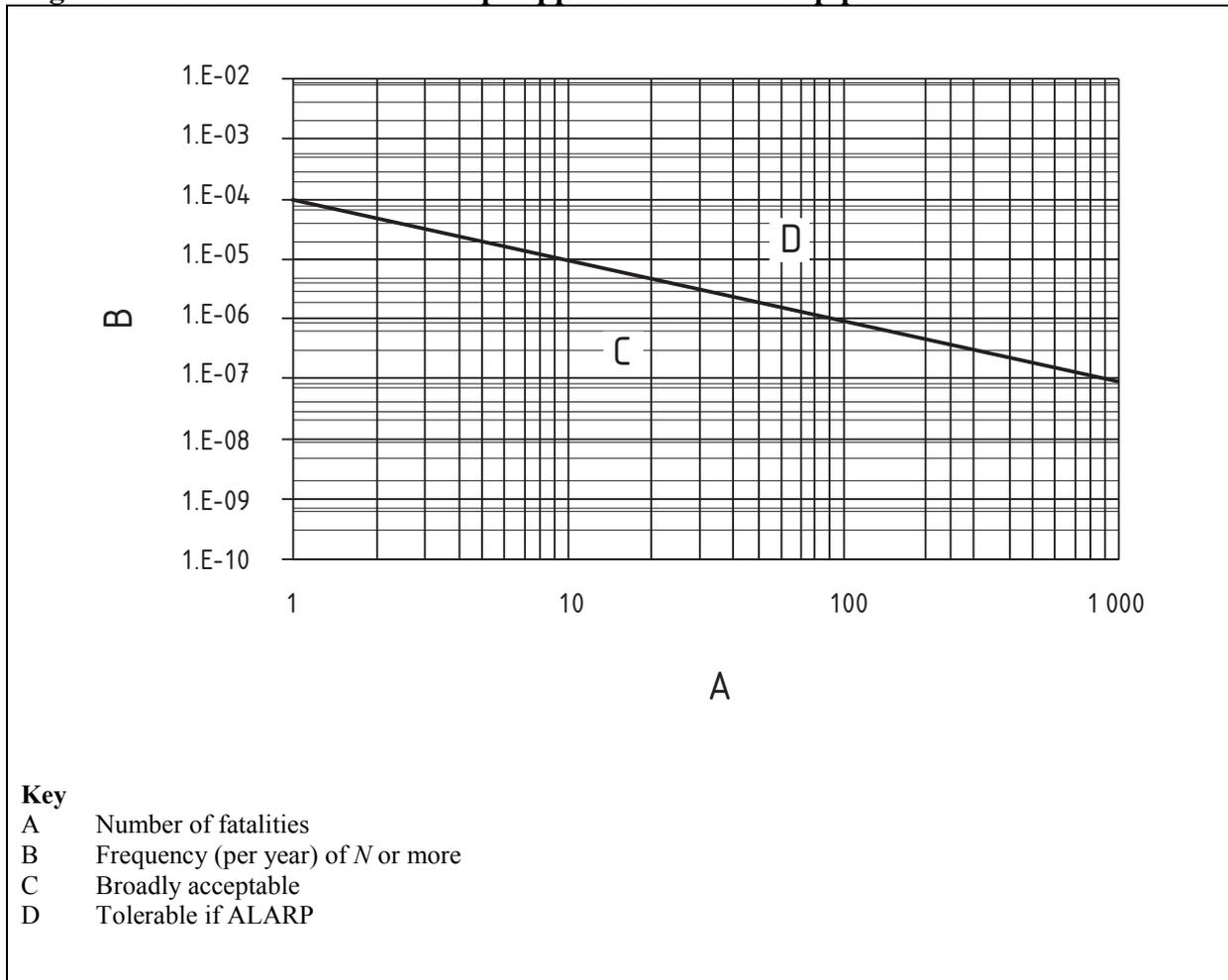
Societal risk is expressed graphically as an *FN* diagram, showing the cumulative frequency *F* (usually per year) of accidents causing *N* or more fatalities. For application to pipelines, it is necessary to specify a length over which the frequency and consequences of all accident scenarios are collated.

The *FN* criterion which should be used to assess societal risk due to MAHPs is given in Figure 8. This allows assessment of the residual risk to the average Class 1 population density (i.e. 2.5 persons per hectare) adjacent to each 1 km length of pipeline, in a strip centred on the pipeline of 8 times the building proximity distance or twice the distance to the  $(0.3 \times 10^{-6})$

risk level. In effect it represents the upper limit of the cumulative frequency of multiple fatality accidents in any 1 km section of a pipeline route. In the assessment of societal risk, the methodology applied should be consistent with the criterion in terms of the length of pipeline considered. The *FN* criterion shown here is applicable to assessments carried out using 1 800 tdu, equivalent to a significant likelihood of causing fatality (approximately 25%).

*NOTE 1* The *FN* envelope in Figure 9 represents broadly acceptable risk levels and therefore relevant good practice in both location classes 1 and 2.

**Figure 8 – Societal risk *FN* envelope applicable to 1 km of pipeline**



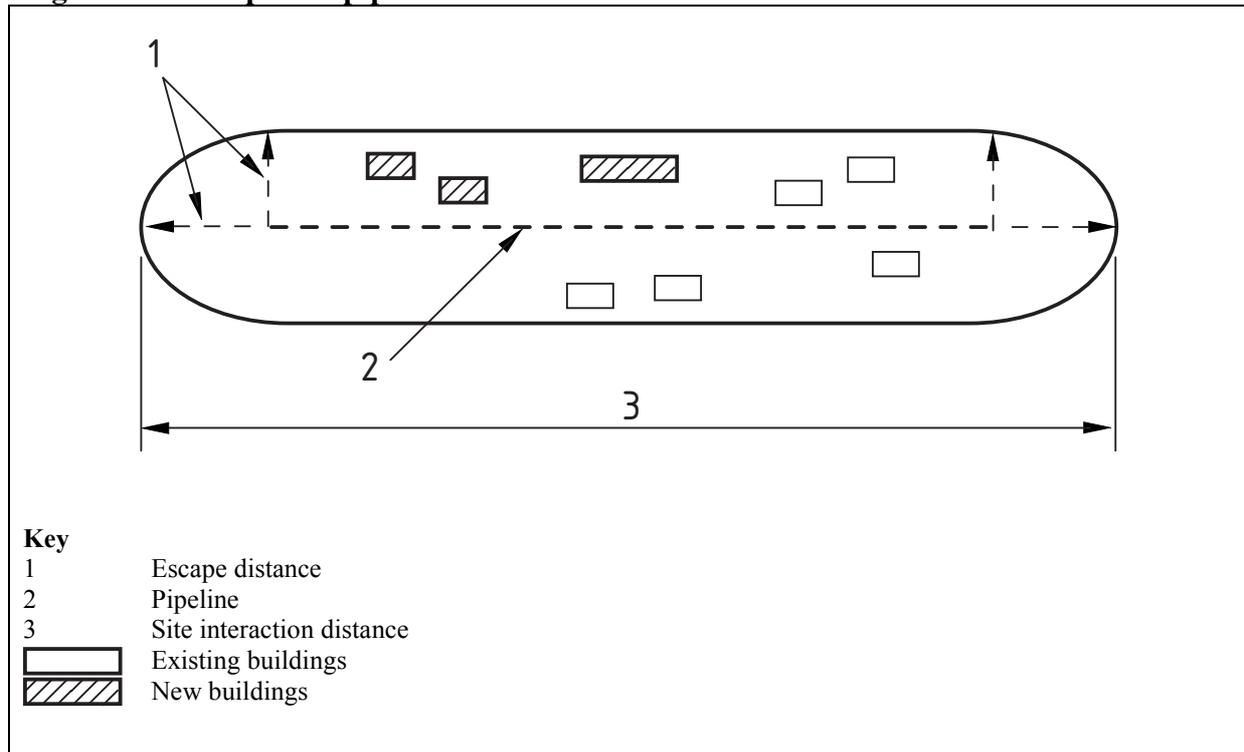
Population density is not usually equally spread, so in some cases “clusters” of population occur along a pipeline route. Assessment of the societal risk in accordance with the *FN* envelope might still allow this to be classified as an acceptable situation not requiring any upgrading of the pipeline to reduce the risk.

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

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, e.g. the site length combined with the escape distance for thermal radiation (see Figure 9). This is defined as the site interaction distance.

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 defined by the pipeline section and the interaction distance (see Figure 10) determined. The frequency,  $f$ , and effect area for each accident scenario is then assessed 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  $fN$  pairs, which are then ordered with respect to increasing number of casualties,  $N$ , and the cumulative frequency,  $F$ , of  $N$  or more people being affected is determined, giving a site-specific  $FN$  curve.

**Figure 9 – Site-specific pipeline interaction distance**



The site-specific  $FN$  curve should be compared with the  $FN$  envelope in Figure 8. As the envelope relates to a 1 km length of pipeline, the site-specific  $FN$  criteria are obtained by factoring risk values by a factor equal to 1 km divided by the interaction length.

The  $FN$  criterion envelope given in Figure 9 represents broadly acceptable risk levels for pipeline operation. If the calculated site-specific  $FN$  curve is within the  $FN$  criterion envelope, the risk levels to the adjacent population are considered broadly acceptable. If the site-specific  $FN$  curve is close to or exceeds the  $FN$  criterion curve, then further mitigation might be required to reduce risks to acceptable/negligible levels if this is economically possible, or the proposed development might be deemed unacceptable in generating excessive societal risk levels.

If the specified area of interest includes another pipeline, the risk from this pipeline should be included in the assessment if it is considered that:

- the pipelines can interact such that a failure on one pipeline would lead to the failure of the other pipeline;
- the site under consideration is within the interaction distances of all pipelines in the specified area.

If pipeline interaction is considered likely then expert opinion should be obtained on how to model the combined failure frequencies and product outflow. The pipelines should be individually assessed and the risk from each summed to obtain overall individual risk transects and societal risk *FN* curves.

When assessing multiple pipelines, *FN* data should be obtained for each pipeline assessed. When calculating the overall risk it is necessary to combine the individual *FN* pairs from each assessment. This data is then factored by a value equal to 1 km divided by the sum of the interaction lengths for each pipeline considered and compared to the *FN* criterion envelope.

## Annex A (informative)

### Summary of HSE methodology for provision of advice on planning developments in the vicinity of major accident hazard pipelines in the UK

#### A.1 Land use planning zones

The Health and Safety Executive (HSE) sets land use planning zones for major hazard sites including high-pressure pipelines transporting defined hazardous substances, so that it can provide advice to the local planning authorities on the risks posed by major hazards to people in the surrounding area.

Land use planning zones are used by HSE for MAHPs as defined by Regulation 18 and Schedule 2 of the Pipeline Safety Regulations 1996 [1], and to pipelines that were notified under the Notification of Installations Handling Hazardous Substances Regulations 1982 [2] before the enactment of the Pipeline Safety Regulations 1996.

Land use planning zones define three areas:

- inner zone, which is immediately adjacent to the pipeline;
- middle zone, which applies to significant development;
- outer zone, which applies to 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 the HSE by the pipeline operator. HSE then notifies the inner, middle and outer zone distances to local planning authorities. The outer zone distance is also called the consultation zone, within which the risk implications of planning developments have to be considered by the local authority.

Local planning authorities in Great Britain are responsible for land use planning decisions under the Town and Country Planning Act 1990 [3], and the HSE is a statutory consultee with responsibility to provide advice with respect to public safety for any 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 available from the HSE website entitled *Planning advice for developments near hazardous installations (PADHI+)* [4].

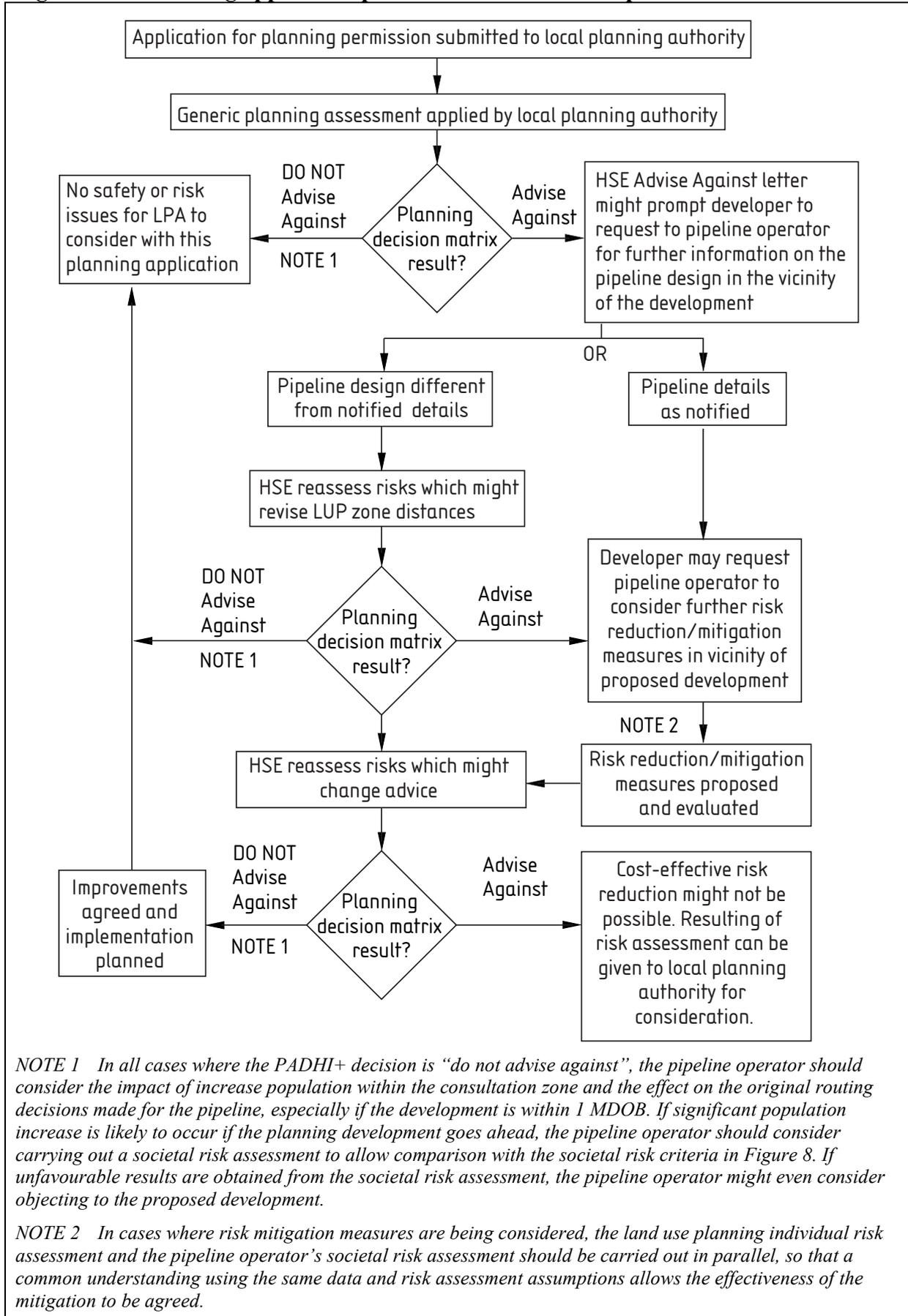
A developer or local planning authority might wish to seek further information to see whether the risk at the specific development location is different from the generalized land use planning zone notified by HSE, or whether additional risk reduction measures (risk mitigation) can be applied at that location, to allow the planned development to proceed. Land use planning zones notified to local planning authorities 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 (e.g. thicker walled pipe or slabbing) near the proposed development, a detailed risk assessment is carried out by HSE to assess any change to zone boundaries.

At the time when the pipeline operator becomes aware of the possibility of a development near the pipeline, especially if it involves an increase in population within 1 MDOB, they should assess the population increase against original routing parameters. In some cases they might decide to initiate a full societal risk assessment to define acceptability or otherwise of the development against the societal risk curve presented in Figure 8.

In these cases, there is a requirement to re-assess the impact of site-specific details on the risk levels within the land use planning zones set by HSE using an established risk assessment methodology. The guidance in this part of PD 8010 is provided for use by pipeline operators, local planning authorities, developers and any person involved in the risk assessment of developments in the vicinity of existing MAHPs. It is based on the established best practice methodology for pipeline risk assessment.

It is recommended that the methodology be used for the prediction of site-specific risk levels for consideration in the reassessment of land use planning developments, so that specific local conditions can be taken into account. The process is shown in Figure A.1.

**Figure A.1 – Planning application process and need for site-specific risk assessment**



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:
- 1) an individual risk of  $(1 \times 10^{-5})$  per year of dangerous dose or worse to the average householder; or
  - 2) the pipeline MDOB;

*NOTE 1 Calculation of pipeline risks indicates that the maximum risk on an MAHP does not reach a risk level of  $1 \times 10^{-5}$  per year and is therefore not expected to attract an inner zone. However, other risks can apply (e.g. debris or overpressure from pipe burst, flammable gas cloud near to release point), so an inner zone equivalent to the MDOB has been applied by the HSE to MAHPs. This distance is calculated using the equation and substance factors given in PD 8010-1:2004, 5.5.3.*

*NOTE 2 In the past, HSE has used a consequence based approach for calculating this distance*

- b) boundary between middle zone and outer zone – an individual risk of  $(1 \times 10^{-6})$  per year of dangerous dose or worse to the average householder;
- c) boundary between outer zone and no restrictions – the lesser of:
- 1) an individual risk of  $(0.3 \times 10^{-6})$  per year of dangerous dose or worse to the average householder;
  - 2) four-thirds of the middle zone distance from the pipeline.

*NOTE 3 In cases where the calculation of risks indicates risk levels are lower than  $(1 \times 10^{-6})$  per year and therefore there is no middle zone, the inner and middle zones are made equal to the MDOB. Similarly, where risk calculations show levels lower than  $(0.3 \times 10^{-6})$  per year, all three zones, inner, middle and outer, are made equal to the MDOB (PD 8010-1:2004, 5.5.3).*

*NOTE 4 The location of sensitive developments (e.g. hospitals, schools, old people's homes) is restricted to the outer zone (see also Clause 8).*

MDOBs are given in PD 8010-1:2004, 5.5.3. In the case of mixtures, it might be appropriate to take into account proportions when calculating this distance.

Dangerous dose is defined by HSE as a dose of thermal radiation that would cause:

- 1) severe distress to almost everyone in the area;
- 2) a substantial fraction of the exposed population requiring medical attention;
- 3) some people being seriously injured, requiring prolonged treatment;
- 4) any highly susceptible/sensitive people being killed.

*NOTE 5 Due to the uncertainties associated with such predictions, the use of the "dangerous dose" concept is used by HSE to define land use planning zones. Normally, a "dangerous dose" for thermal radiation is defined as 1 000 tdu. These criteria are based on the assumption that the exposed people are clothed normally and in the open.*

There are a number of aspects of the HSE land use planning and major hazards work that PADHI+ [4] does not deal with, including developments near pipelines, where the pipelines have sections with additional protection measures. PADHI+ uses the three zones set by HSE that are based on the details given in the pipeline notification. In cases where local pipeline details differ from notified details, then HSE risk assessors might be willing to reconsider the case using the details relevant to the pipeline near the development.

## A.2 Distances to risk zones

Current HSE land use planning distances to ( $1 \times 10^{-6}$ ) and ( $0.3 \times 10^{-6}$ ) risk contours for ethylene, spiked crude and natural gas liquids (NGLs) are given in Table A.1.

Zone distances based on these risk levels notified to the local planning authorities are as calculated by HSE, and therefore may differ from equivalent risk levels calculated using other methodologies. Where possible, specific assumptions made by HSE are given in this document, so that the effect may be quantified.

**Table A.1 – Typical  $10^{-6}$  and ( $0.3 \times 10^{-6}$ ) risk contours for ethylene, spiked crude and natural gas liquids (NGLs)**

Content of pipeline	Distances to risk zones					
	MAOP bar	Diameter mm	Wall thickness mm	Material <sup>A)</sup>	Distance to $10^{-6}$ m	Distance to $0.3 \times 10^{-6}$ m
Ethylene	95	219	7.03	X42	150	200
Ethylene	95	273	7.09	X52	190	240
Ethylene	99	273	5.56	X52	240	300
Spiked crude	64	914	9.52	X65	380	435
NGL	69	508	9.52	X52	432	485

<sup>A)</sup> As specified in ISO 3183-2:1996.

## A.3 Specific HSE methods and assumptions

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

### A.3.1 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.

### A.3.2 Probability of ignition

Typical overall probabilities for flammable gases used by HSE are:

- immediate ignition resulting in a fireball followed by jet fire: 0.2;
- delayed ignition resulting in a jet fire: 0.64 ;
- delayed ignition resulting in a flash fire followed by a jet fire;;
- no ignition: 0.16 .

*NOTE Other probabilities are observed in historical data.*

### A.3.3 Thermal radiation and effects

HSE assumes that the typical person will move away from the fire at a speed of 2.5 m/s and will find shelter at a distance of 75 m in a class 1 environment or at a distance of 50 m in a class 2, provided the thermal radiation dose they receive does not exceed 1 000 tdu. If the cumulative thermal dose of 1000 tdu is exceeded for an average population, then casualties

are assumed to occur. A lower limit thermal radiation level of  $1 \text{ kW/m}^2$  is applied in some cases.

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 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. People inside buildings engulfed by pool 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 people indoors during the day is 90%, and the proportion at night is 99%.

**Annex B (informative)**

**Probability of failures and failure frequencies for UK pipelines**

**B.1 All damage mechanisms**

Pipeline failure frequencies for UK pipelines derived from data published by UKOPA are given in Table B.1.

**Table B.1 – Failure rates for UK pipelines based on UKOPA data**

Units in failure frequency per 1 000 km-y

Damage mechanism	Pin <sup>A)</sup>	Hole <sup>B)</sup>	Rupture <sup>C)</sup>	Total
Third-party interference	0.006	0.04	0.011	0.057
External corrosion	0.035	0.009	0.002	0.046
Internal corrosion	0.003	0	0	0.003
Material and construction	0.063	0.013	0	0.076
Ground movement	0.003	0.004	0.002	0.009
Other	0.052	0.019	0.002	0.073
<b>Total</b>	—	—	—	<b>0.264</b>

A) Equivalent diameter up to 6 mm.

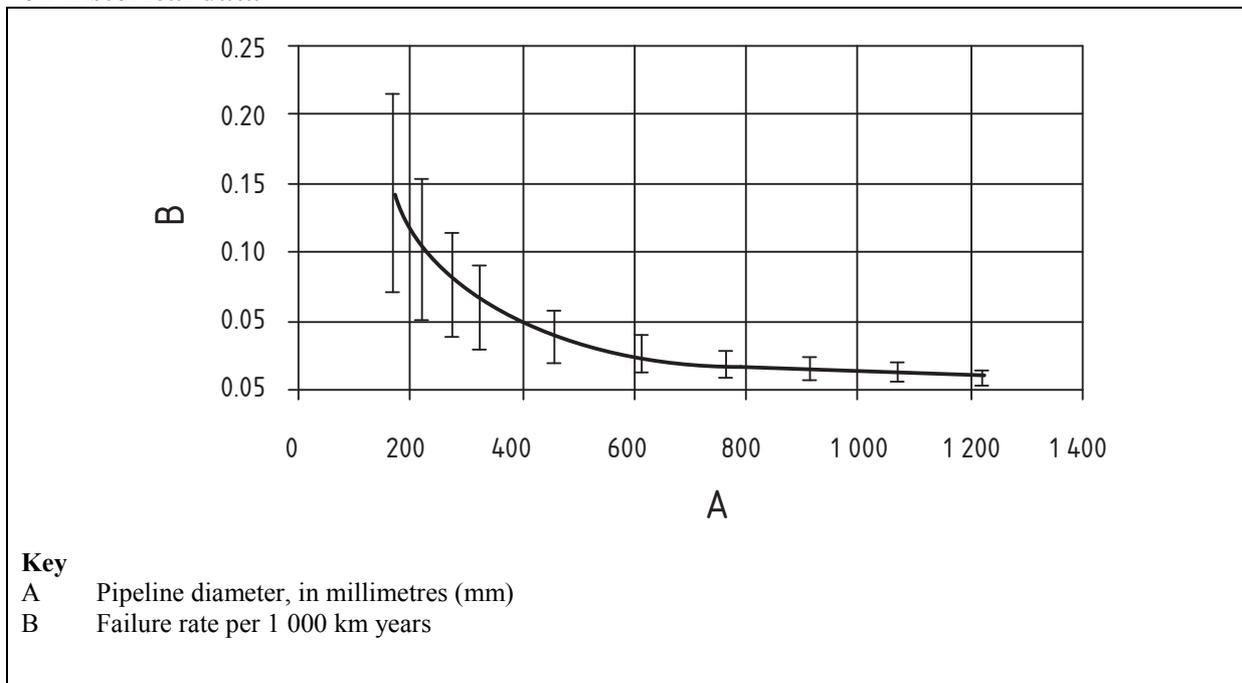
B) Equivalent diameter greater than 6 mm but less than pipe diameter.

C) Equivalent diameter equal to or greater than pipe diameter.

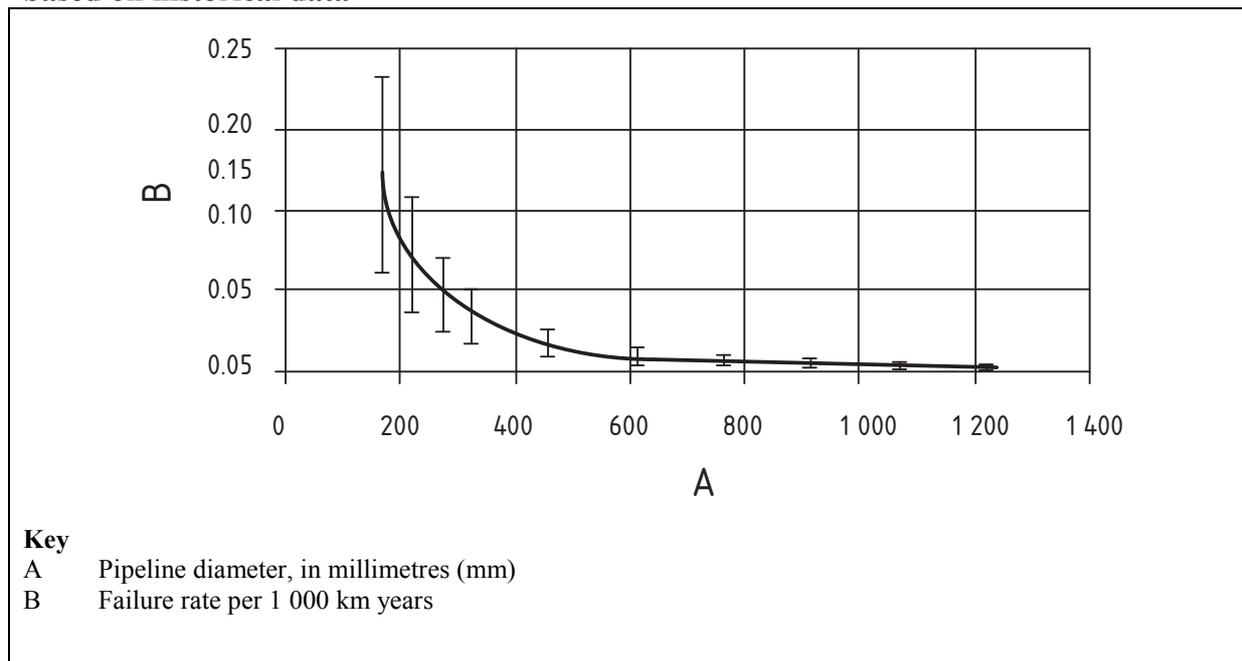
*NOTE Application of pipeline failure rates in a site-specific risk assessment requires careful consideration of local details.*

Typical total and rupture-only failure frequencies based on historical and predictive data are given in Figures B.1 and B.2. The figures indicate the variation of typical frequencies due to variations in design factor (pressure and material grade) and wall thickness.

**Figure B.1 – Typical total pipeline failure frequencies for all damage mechanisms based on historical data**



**Figure B.2 – Typical rupture pipeline failure frequencies for all damage mechanisms based on historical data**



### B.2 Prediction of pipeline failure frequency due to third-party interference

Pipeline damage due to 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 for generic pipeline cases, which can then be modified to take account of the design factor and wall thickness of a specific case. A generic pipeline failure frequency curve proposed by UKOPA is given in **B.3**, together with a worked example demonstrating how it can be used with the reduction factors for design factor and wall thickness given in Figure 4 and Figure 5 respectively to obtain a reasonable, representative failure frequency prediction for any specified pipeline.

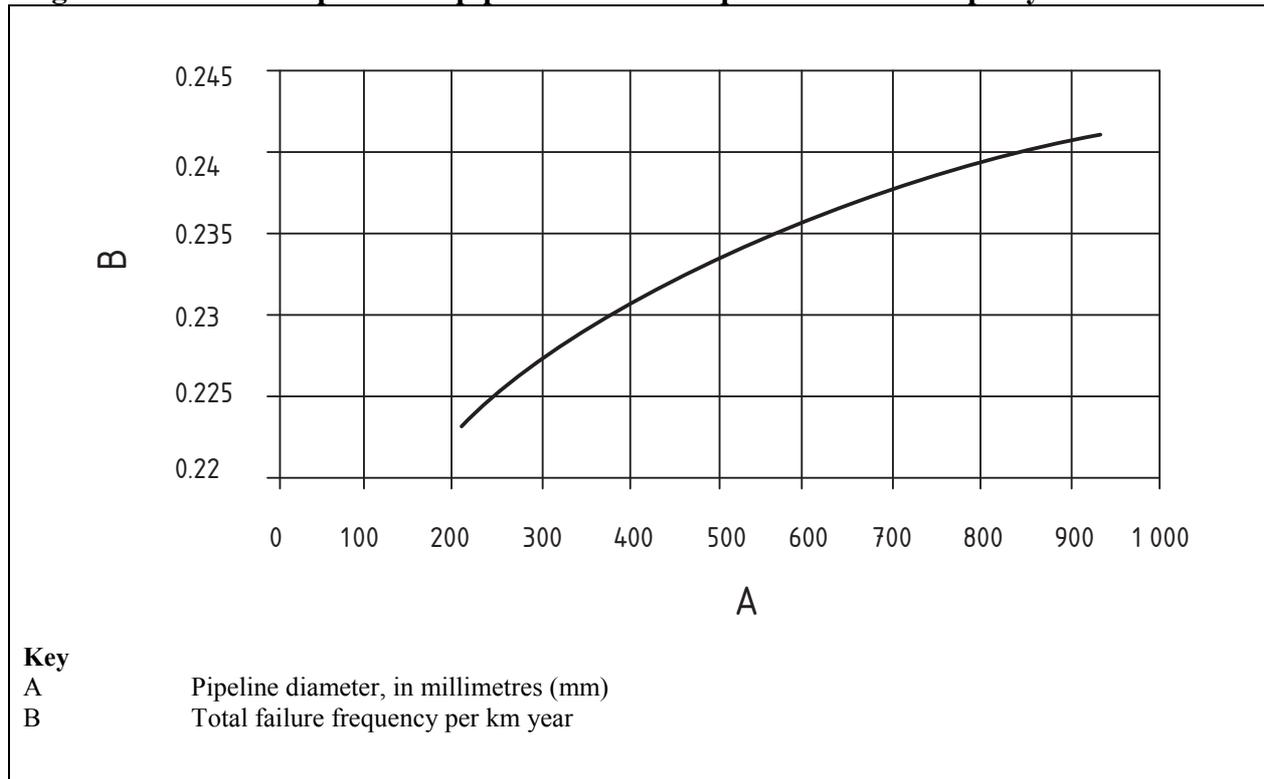
*NOTE Failure frequency predictions based on assessment of current operational fault and failure data are published by UKOPA.*

### B.3 Generic pipeline failure frequency curve

A generic pipeline failure frequency curve which can be used with the failure frequency reduction factors for design factor and wall thickness given in Figure 4 and Figure 5 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. This curve is shown in Figure B.3.

*NOTE 1 Predicted failure frequencies due to third-party interference increase with material grade, so the generic curve given in Figure B.3 can be conservatively applied to pipelines with material grades of X65 and lower.*

**Figure B.3 – Generic predicted pipeline failure frequencies for third-party interference**



For high pressure gas releases, the critical defect size at which the failure mode changes from leak to rupture needs to be considered. Typical values of the critical defect size given as equivalent hole diameter for pipelines operating at a design factor of 0.72 are given in Table B.2.

**Table B.2 – Critical defect size given as equivalent hole diameter for pipelines operating at design factor 0.72 with material grade X65**

Dimensions in millimetres

Diameter	Wall thickness	Critical hole diameter relating to the leak/rupture limit
219	4.56	2.53
273	5.69	3.16
324	6.75	3.75
406	8.45	4.12
457	9.52	4.69
610	12.7	5.28
762	15.88	5.87
914	19.04	7.05

Figure B.3 shows that a 219 mm diameter pipeline with a wall thickness of 5 mm has a failure frequency of 0.224 per 1 000 km·y.

The generic failure frequency curve can be used together with the reduction factors given in Figure 4 (design factor) and Figure 5 (wall thickness) to derive the failure frequency for a 219 mm × 6.4 mm wall thickness pipeline operating at a design factor of 0.5 as follows:

- a) the reduction due to a design factor of 0.5 from 0.72 is obtained as 0.5 from Figure 4,

- b) the reduction due to wall thickness of 6.4 mm from 4.56 mm is obtained as 0.61 from Figure 5.

*NOTE 2 This is conservative, as the reduction factor curve shown in Figure 5 is based on a minimum wall thickness of 5 mm.*

The estimated total failure frequency for the pipeline example,  $f$  (219 mm diameter, 6.4 mm wall thickness, design factor 0.5), is therefore:

$$\begin{aligned} f &= 0.224 \times 0.5 \times 0.61 \\ &= 0.068 \text{ per } 1\,000 \text{ km}\cdot\text{y} \end{aligned}$$

Comparison of this estimated failure frequency with the typical pipeline failure frequency rates given in Figure B.1 shows that the estimated frequency falls within the range variation and is below the mean curve.

## Annex C (informative)

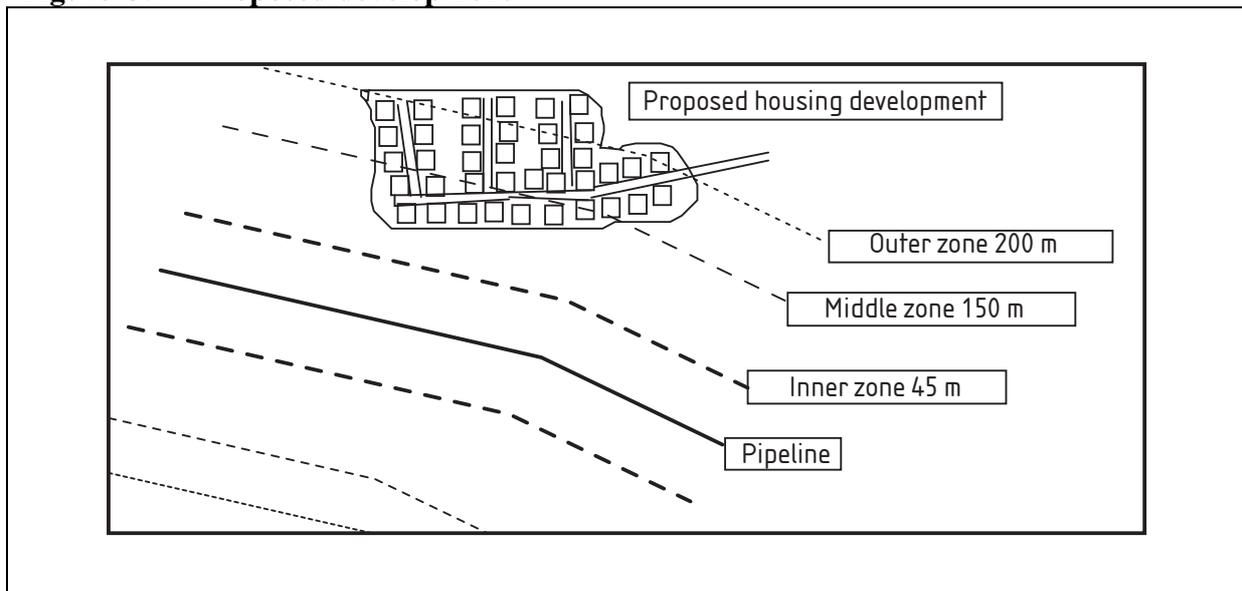
### Example of a site-specific risk assessment

#### C.1 Scenario

A planning application for a housing estate consisting of 38 houses in a green field rural area near a village has been lodged with the local planning authority. On checking their records, the planning authority finds that there is an ethylene pipeline located near the proposed site which has land use planning zones. The closest house is 100 m from the pipeline.

Details are shown in Figure C.1.

**Figure C.1 – Proposed development**



The planning authority checks pipeline risk zones against advice from the Regulatory Safety Authority (RSA), 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 RSA advice against allowing this development to proceed.

The planning authority therefore informs the developer that they will refuse planning permission on safety grounds.

The developer therefore contacts the pipeline operator to see whether there are any special conditions associated with the pipeline that could affect the planning application. After discussion with the operator, the developer is able to confirm that the pipeline design conditions are as notified to the RSA and therefore the only possibility would be to apply mitigating factors to reduce the risk zones.

#### C.2 Risk assessment

The developer commissions a risk assessor to review the land use planning zones and possible mitigation that could be applied.

The following details are confirmed:

- product: ethylene (dense phase);
- pipeline diameter: 219 mm;
- wall thickness: 7.03 m;

- steel: X42;
- maximum allowable operating pressure: 95 bar;
- depth of cover: 1 100 mm;
- area classification: class 1 (rural).

From this the design factor is calculated as 0.51.

Reading off failure rates from Annex B:

- rupture failure rate: 0.07 per 1 000 km years;
- total failure rate: 0.12 per 1 000 km years;
- minimum distance to occupied buildings: 45 m.

For this pipeline, it is estimated that third-party interference accounts for 65% of failures.

The risk assessor is able to simulate risks from the following main calculation steps:

- fireball radius: 54 m;
- fireball duration: 8 s;
- fireball spontaneous ignition distance: 73 m;
- fireball 1 000 tdu in open air distance: 104 m;
- rupture 30 s jet flame escape distance: 106 m.

From this the distance to risk levels are calculated as follows:

- $10^{-6}$  per year individual risk: 150 m;
- $3 \times 10^{-7}$  per year individual risk: 340 m.

These risk levels correspond well to RSA land use planning zones:

- inner zone: 45 ms (i.e. MDOB);
- middle zone: 150 m;
- outer zone: 200 m (limited to four-thirds of the middle zone).

### **C.3 Mitigation measures**

#### **C.3.1 Possible measures**

The following possible mitigation measures are proposed for risk reduction:

- a) install concrete slabbing and marker tape over the pipeline;
- b) re-lay pipeline in heavy-wall pipe.

These measures are discussed in **C.3.2** and **C.3.3** respectively.

#### **C.3.2 Installing concrete slabbing and marker tape over the pipeline**

This is assumed to reduce the third-party failure frequency by a factor of 0.1 in this case

Third-party failures account for 65% of failures. The new failure rates are therefore:

- rupture failure rate: 0.029 per 1 000 km years;
- total failure rate: 0.05 per 1 000 km years.

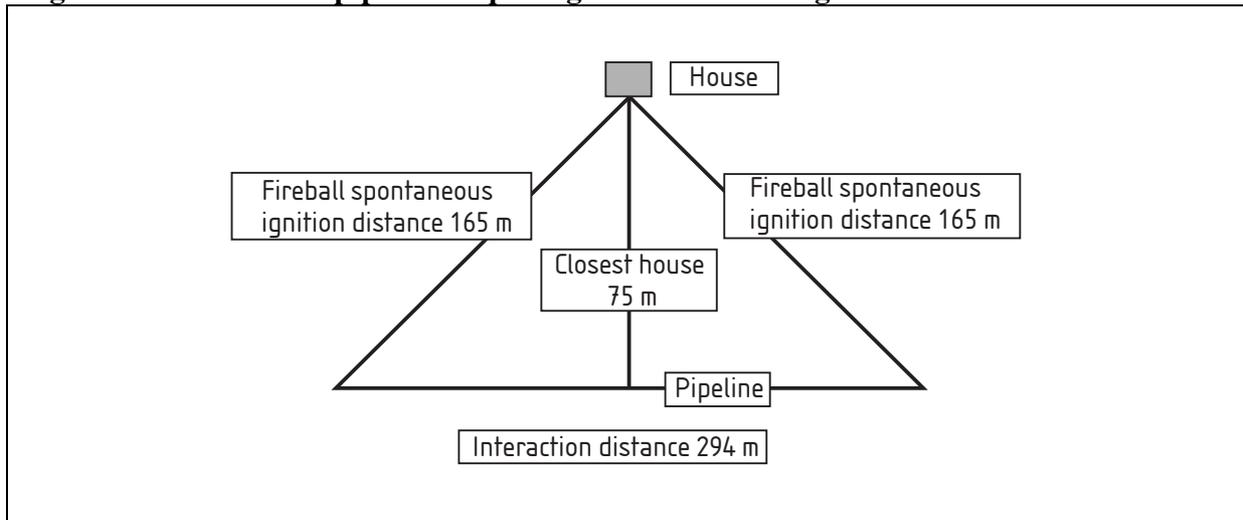
The re-calculated risk distances are:

- $10^{-6}$  per year individual risk: 95 m;
- $3 \times 10^{-7}$  per year individual risk: 210 m.

This would reduce the middle zone so that all the new development is outside the middle zone, and so it might be possible for this to change the planning advice.

However, the concrete slabbing would be required of the maximum interaction distance defined in Figure 3, which could affect the nearest house which is 75 m from the pipeline – a distance of 294 m as shown in Figure C.2.

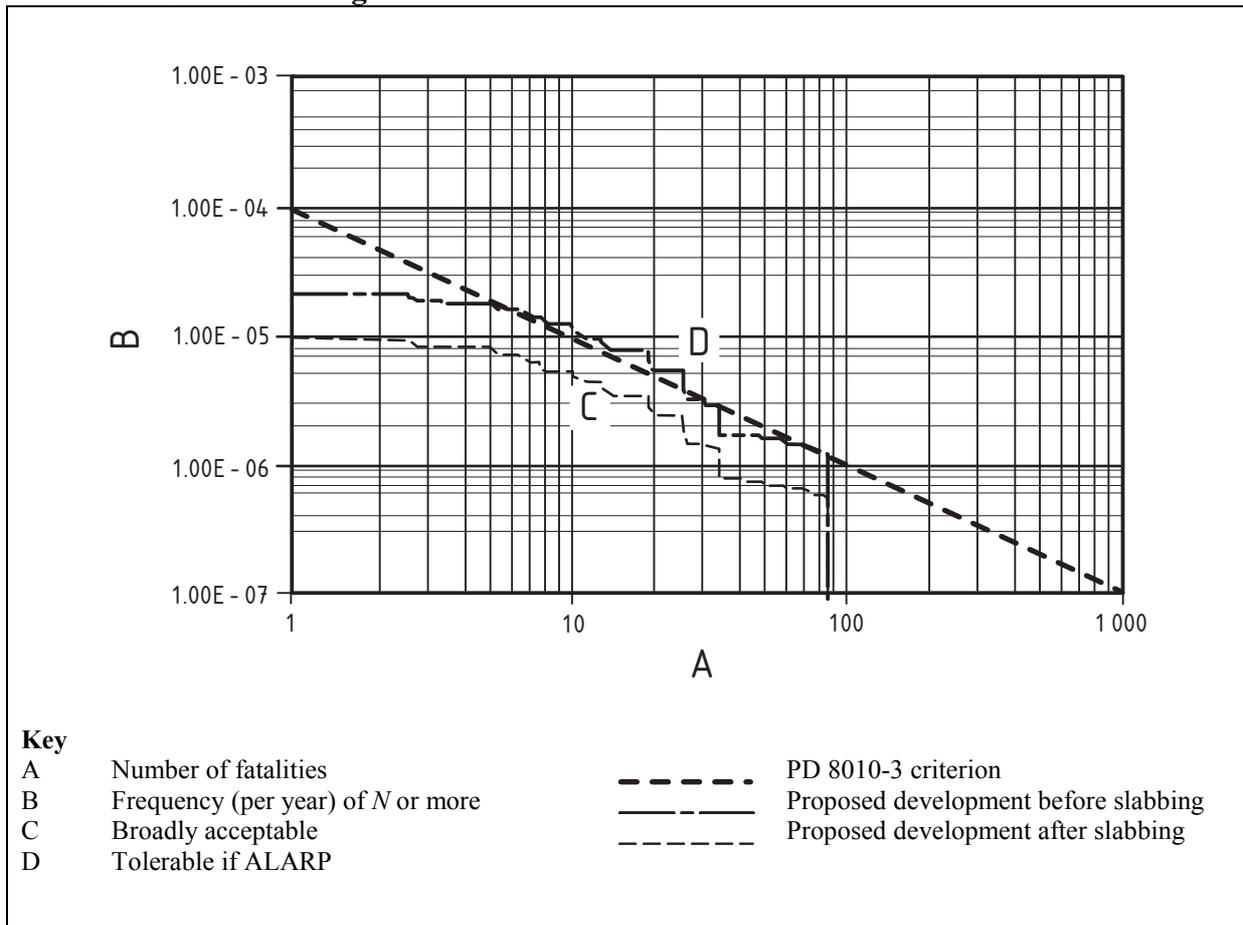
**Figure C.2 – Extent of pipeline requiring concrete slabbing**



*NOTE If public gathering areas were identified in the new housing development, then the distance to the outdoor thermal radiation effect distance (262 m) would be used in this calculation.*

The operator also requests a societal risk assessment for the situation before slabbing and after slabbing to be able to assess the risk reduction achieved. The resulting graph is shown in Figure C.3.

**Figure C.3 – Societal risk FN curves and PD 8010-3 criterion – proposed development before and after slabbing**



Measured against the 1 km societal risk criterion for an interaction distance of 450 m, and applying the thermal radiation level of 1 800 tdu for comparison with this criterion, this indicates that the proposed development was above the “negligible/tolerable” risk criterion line, whereas after slabbing the risk has reduced so that all risks are within the “negligible/acceptable” region.

## Bibliography

For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

### Standards publications

PD 8010-2, *Code of practice for pipelines – Part 1: Subsea pipelines*

ISO 3183-2:1996, *Petroleum and natural gas industries – Steel pipe for pipelines – Technical delivery conditions – Part 2: Pipes of requirements class B*

IGE/TD/1 Edition 4:2001, *Steel pipelines for high pressure gas transmission.*<sup>3)</sup>

### Other publications

- [1] GREAT BRITAIN. Pipelines Safety Regulations 1996. London: HMSO.
- [2] ACTON, M., BALDWIN, T., and JAGER, E.R. *Recent developments in the design and application of the PIPESAFE risk assessment package for gas transmission pipelines* Proceedings of IPC 2002: International Pipeline Conference 29 Sep – 3 Oct 2002, Calgary, Canada.
- [3] GREAT BRITAIN. Notification of Installations Handling Hazardous Substances Regulations 1982 and subsequent amendments. London: HMSO.
- [4] GREAT BRITAIN. Town and Country Planning Act 1990. London: HMSO.
- [5] HEALTH AND SAFETY EXECUTIVE. *Planning advice for developments near hazardous installations (PADHI+)*. London: Health and Safety Executive.<sup>4)</sup>
- [6] LYONS, D. *Western European cross country oil pipelines 30 year performance statistics*. Report 1/02. Brussels: CONCAWE, February 2002.<sup>5)</sup>
- [7] EUROPEAN GAS PIPELINE INCIDENT DATA GROUP. *Gas pipeline incidents – 6th report of the European Gas Pipeline Incident Data Group 1970–2004*. EGIG 05 R.0002. European Member States: EGIG, December 2005.<sup>6)</sup>
- [8] BROWNE, D. AND HICKS, R. *Pipeline product loss incidents 1962–2004 – 4th report of the UKOPA Fault Data Management Group*. Advantica Report R8099. Loughborough: Advantica, April 2005.<sup>7)</sup>

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<sup>3)</sup> Institution of Gas Engineers and Managers (formerly Institution of Gas Engineers) (IGE) standards are available from the Institution of Gas Engineers and Managers, Charnwood Wing, Holywell Park, Ashby Road, Loughborough, Leicestershire LE11 3GR.

<sup>4)</sup> This document does not carry a publication date. It is available for downloading at <http://www.hse.gov.uk/landuseplanning/index.htm>.

<sup>5)</sup> Available for downloading at <http://www.concawe.org>.

<sup>6)</sup> Available for downloading at <http://www.egig.nl/>.

<sup>7)</sup> Available for downloading at <http://www.ukopa.co.uk/publications>.