Penspen Integrity
Units 7-8
St. Peter's Wharf
Newcastle upon Tyne
NE6 1TZ
United Kingdom

Telephone: +44 (0)191 238 2200
Fax: +44 (0)191 275 9786
Email: integrity.ncl@penspen.com
Website: www.penspenintegrity.com

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# DEVELOPMENT OF RISK ASSESSMENT CODE SUPPLEMENTS FOR THE UK PIPELINE CODES IGE/TD/1 AND PD 8010

**Graham D. Goodfellow**
Penspen Ltd.
Newcastle upon Tyne, UK
g.goodfellow@penspen.com

**Dr. Jane V. Haswell**
Pipeline Integrity Engineers Ltd.
Newcastle upon Tyne, UK
jane.haswell@pieuk.co.uk

**Prof. Rod McConnell**
Pipeline Integrity Engineers Ltd.
Newcastle upon Tyne, UK
rod.mcconnell@pieuk.co.uk

**Neil W. Jackson**
National Grid
Warwick, UK
neil.w.jackson@uk.ngrid.com

## ABSTRACT

The United Kingdom Onshore Pipeline Operators Association (UKOPA) was formed by UK pipeline operators to provide a common forum for representing pipeline operators interests in the safe management of pipelines. This includes ensuring that UK pipeline codes include best practice, and that there is a common view in terms of compliance with these codes.

Major hazard cross country pipelines are laid on 3rd party land, and in general have an operational life typically greater than 50 years. The land use in the vicinity of any pipeline will change with time, and buildings will be constructed adjacent to the pipeline route. This can result in population density and proximity infringements, and the pipeline becoming non-compliant with the code. Accordingly, a land use planning system is applied so that the safety of, and risk to, developments in the vicinity of major hazard pipelines are assessed at the planning stage. In the UK, the Health & Safety Executive (HSE) are statutory consultees to this process, and they set a quantitative risk-based consultation zone around major hazard pipelines, where the risks to people and developments must be assessed.

Quantitative risk assessment (QRA) requires expertise, and the results obtained are dependent upon consequence and failure models, input data, assumptions and criteria. UKOPA has worked to obtain cross-stakeholder agreement on how QRA is applied to land use planning assessments. A major part of the strategy to achieve this was the development of supplements for the UK design codes IGE/TD/1 and PD 8010, to provide authoritative and accepted guidance on the risk analysis of:

i) Site specific pipeline details, for example increased wall thickness, pipeline protection (such as slabbing), depth of cover, damage type and failure mode, and
ii) The impact of mitigation measures which could be applied as part of the development.

The availability of this codified advice would ensure a standard and consistent approach, and reduce the potential for disagreement between stakeholders on the acceptability of proposed developments.

This paper describes the guidance given in these code supplements in relation to consequence modelling, prediction of failure frequency, application of risk criteria, implementation of risk mitigation and summarises the assessment example provided.

## 1. INTRODUCTION

### *UKOPA*

The United Kingdom Onshore Pipeline Operators Association (UKOPA) was founded in 1997 to represent the views and interests of UK pipeline operators responsible for major accident hazard pipelines (MAHPs) regarding safety, legislative compliance and best practice. Its members include:

- BP
- BPA
- Centrica Storage

- Eon
- ExxonMobil
- National Grid
- Northern Gas Networks
- OPA
- Sabic
- Scotland Gas Networks
- Shell
- Total
- Unipen
- Wales & West Utilities

A strategic aim of UKOPA has been to achieve agreement with all stakeholders in pipeline quantitative risk assessment (QRA) methodologies, and the inputs and assumptions applied in the assessment, so that consistency in decisions on land use planning can be achieved.

### *Management and Operation of Hazardous Pipelines in the UK*

Pipelines in the UK are designed, built, operated and managed in accordance with the goal-setting Pipeline Safety Regulations 1996 (PSR 96)[1] which set out duties to ensure that risk levels from pipelines are "as low as reasonably practicable" (ALARP). The guidance to these regulations[2] states that British Standards provide a sound basis for the design of pipelines, but other national or international standards or codes are acceptable provided that they give an equivalent level of safety.

Prior to the discovery of North Sea gas, and the subsequent development of long distance gas transmission pipelines in the UK, in the 1960s, UK pipeline codes[3] were simple interpretations of ASME B31 codes.

UK codes[4, 5] were based on North American experience, but since the 1960s they were updated to accommodate a higher level of land development and higher population densities. This led to changes to these codes, including material properties, fracture propagation and the need for high-level pre-commissioning testing. Also added was the use of a 'building proximity distance' (BPD), the minimum separation distance between occupied buildings and the pipeline calculated as a function of pressure and diameter.

These additional requirements have proved successful as they have maintained broadly similar individual risk levels to pipelines designed to ASME B 31.8[6] despite the higher population density in the UK[7].

Pipelines are long-life assets located on 3rd party land and changes in land use adjacent to the pipeline are likely to occur over time which can result in increases in population density and buildings constructed in close proximity to the pipeline. This can result in the pipeline becoming non-compliant with the code.

The UK codes therefore require the pipeline operator to assess changes along the route to identify situations where the pipeline no longer complies with the code routing and design requirements, and may pose unacceptable risks to the population. In such cases, the codes require that QRA is applied to assess whether the risk is acceptable.

Where risk levels are considered to be unacceptable, risk mitigation measures must be applied to avoid downrating the pipeline operating pressure. Mitigation measures may involve assessing the protection provided by the local depth of cover, installing pipeline protection (concrete slabbing with marker tape) relaying in thicker wall, or diversion of the pipeline. QRA is used to assess the effectiveness of mitigation and to select the most appropriate in a specific situation. Guidance included in the code supplements aims to ensure the assessment of risk mitigation measures in terms of the risk reductions each measure provides is consistent.

## 2. UK LAND USE PLANNING

Land use planning (LUP) is a multi-disciplinary process which is used to order and regulate the use of land in an efficient and ethical way, for the benefit of the wider population, economy and protection of the environment. The process involves the selection of physical layout, the scale of the development, aesthetics, and impact on landscape, and in particular in the UK, it considers public safety and economic and environmental impact.

The UK Control of Industrial Major Hazard (CIMAH) Regulations[8] established a "Consultation Zone" around Major Hazard chemical sites in which new planning developments had to be sent by Local Planning Authorities to the Health & Safety Executives (HSE) for their advice. Zones were applied to fixed sites during the mid-1980s, and this was extended to hazardous pipelines in the late 1980s.

The consultation zone is now defined in 3 levels:

- the inner zone (IZ), which is immediately adjacent to the hazardous installation or pipeline,
- the middle zone (MZ), which applies to significant developments, and
- the outer zone (OZ), also known as the Consultation Distance (CD), which applies to vulnerable or very large populations.

as shown in Figure 1.

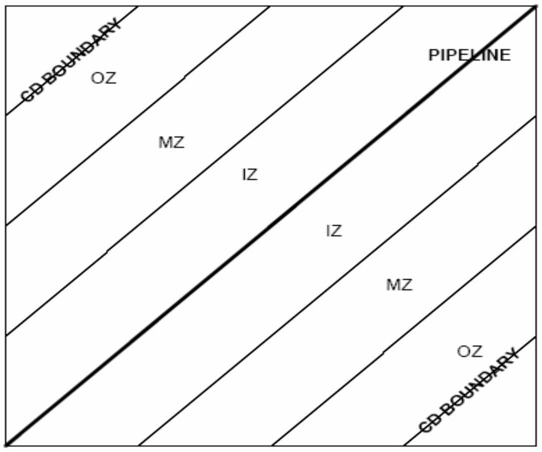


**Figure 1: Consultation Distance and Zones[9]**

### *Planning Advice for Developments near Hazardous Installations*

Inside the zones, planning applications for new housing, shops, or other developments, are assessed by the Local Planning Authority using a process provided by the HSE, called Planning Advice for Developments near Hazardous Installations (PADHI). If application of this process indicates that the risks posed by the hazardous installation or pipeline to the new development are too high, the Local Planning Authority will refuse permission for the development, or the case will be referred to the HSE for a more detailed site-specific assessment.

The PADHI process uses risk-based inner, middle and outer zones and the type of development which is proposed, to assess the acceptability of the development with respect to the pipeline risk. The zones are calculated by the HSE using pipeline details notified by the operators of major accident hazard pipelines as required by PSR 96[1]. The HSE use this information to calculate risk-based distances to the zone boundaries from the pipeline, defining the levels of risk at each zone boundary as follows:

1. boundary between inner and middle zone – based on an individual risk of $1 \times 10^{-5}$ per year;
2. boundary between middle zone and outer zone – an individual risk of $1 \times 10^{-6}$ per year;
3. boundary between outer zone and no restrictions – which is the lesser of:
   - an individual risk of $0.3 \times 10^{-6}$ per year; or
   - a notified outer zone distance.

The individual risk is calculated for the average householder applying a dangerous dose casualty criterion, where dangerous dose is defined by HSE as a dose of thermal radiation that would cause:

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

### *PADHI Decision Matrix*

The PADHI process uses two inputs to a decision matrix to generate an assessment decision:

i) the LUP zone (inner, middle or outer) in which the proposed development is located, and
ii) the 'sensitivity level' of the proposed development, which is derived from an HSE categorisation system of "development types".

Four types of development are defined:

- People at work, parking;
- Developments for use by the general public;
- Developments for use by vulnerable people; and,
- Very large and sensitive developments.

Development types are used as a direct indicator of the sensitivity level of the population at the proposed development. The sensitivity levels are based on a clear rationale in order to allow progressively more severe restrictions to be imposed as the sensitivity of the proposed development increases.

Four sensitivity levels are also defined:

- Level 1 – based on a normal working population
- Level 2 – based on the general public (at home and involved in normal activities)
- Level 3 – based on vulnerable members of the public (children, those with mobility difficulties, or those unable to recognize physical danger)
- Level 4 – large examples of level 3 and large outdoor examples of level 2

The location and sensitivity level of the development are then used to obtain the public safety planning advice from the PADHI decision matrix, which is shown in Table 1.

**Table 1: PADHI Decision Matrix**

| Sensitivity Level | Allowed Developments | | |
|---|---|---|---|
| | Inner Zone | Middle Zone | Outer Zone |
| 1 | DAA | DAA | DAA |
| 2 | AA | DAA | DAA |
| 3 | AA | AA | DAA |
| 4 | AA | AA | AA |

Where:-
DAA = Do not advise against development
AA = Advise against development

PADHI provides a screening process for safety assessments which is based on the standard notified pipeline details. In cases where site specific details differ, for example due to local use of thicker wall pipe, or where the installation of protection is feasible, a site-specific risk assessment is required to confirm whether the local risk levels are acceptable.

To ensure the overall planning process is as efficient and consistent as possible, the risk assessment methodology, assumptions and input data must be standardised where possible.

## 3. DEVELOPMENT OF PIPELINE QRA IN THE UK

IGE/TD/1 requires the operator to carry out a 4 yearly survey of conformity with the design code, including a re-survey of infrastructure surrounding the pipeline, and to take remedial action where infringements to the code are identified. These retrospective actions, rerouting or relaying in thick-walled pipe, can be operationally difficult and expensive to carry out.

The growth in the use of QRA in the UK nuclear and chemical industries, and the development of methods for the prediction of pipeline failure frequency and consequences, led to the application of QRA to pipelines. This showed, in many cases, that the proposed expenditure on modifications appeared to have little or no effect on the predicted risk levels and hence could not be justified.

The risk assessment methodology was used routinely to assess minor code infringements and land use planning issues around gas pipelines and to assist detailed design at specific pipeline locations. The continued development of the assessment methodology, the knowledge of the application of risk assessment to pipeline design and operations, and the increase in availability and power of computers led to the development of the knowledge-based methodology package TRANSPIRE[10] (which has been developed progressively to the present day as PIPESAFE[11, 12]).

The potential for the use of risk assessment in pipeline design was recognised in the British Standard BS 8010 Section 2.8[13] and Edition 3 of IGE TD/1[14].

The TRANSPIRE and PIPESAFE packages were used to derive risk criteria which provided a consistent basis to support code infringements and to respond to land use planning issues. The approach and an example societal risk criterion were included in Edition 4 of IGE/TD/1[4].

The use of Quantified Risk Assessment (QRA) for the safety evaluation of pipelines is now accepted practice in the UK[15], and is used at the design stage of major international pipeline projects.

The advantages of using QRA rather than simple code compliance are that it is a structured and logical approach that quantifies the risk level and allows informed decision making. The disadvantage is that it is complex and requires expert knowledge. Results can be highly dependent upon the input data, assumptions and approach taken.

## 4. DEVELOPMENT OF RISK SUPPLEMENTS

UKOPA identified that there were a range of assumptions, input data and general approaches to QRA in use in the UK and that a codified approach to pipeline risk assessment would have benefit for all stakeholders.

QRA used for routing or to justify code infringements was already included in the IGE/TD/1 and PD 8010 codes, which also include some general guidance on the use of QRA. UKOPA considered that risk supplements to the two codes should be produced to give specific guidance on input data, assumptions and assessment criteria.

The primary purpose of producing supplements to PD 8010 and IGE/TD/1 was to provide authoritative and accepted guidance on the risk analysis of:

i) Site-specific pipeline details, for example increased wall thickness, pipeline protection (such as slabbing), depth of cover, damage type and failure mode, and
ii) Additional risk mitigation measures, which could be applied as part of the development.

The availability of this codified advice would ensure a standard and consistent approach, and reduce the potential for technical disagreement between stakeholders regarding the methods used to assess the acceptability of proposed developments.

The standardised QRA methodology provides guidance on key aspects and assumptions to be used, based on industry best practice. It does not define a specific model or piece of software; however it covers:

- Definition of hazardous substances covered;
- Standard definitions for pipeline failure modes;
- Defined failure scenarios and associated event trees;
- Recognised references for operational failure data;
- Failure frequency prediction models based on the use of recognised operational data;
- Recognised and accepted consequence models;
- Defined mitigation methods and associated risk reduction factors;
- Societal risk criteria; and
- Guidance on application of LUP individual risk criteria.

The code supplements have been developed by the Risk Assessment Working Group (RAWG) of UKOPA over a period of three years and were issued as drafts for public comment in Q2 2007. Following receipt of public comments, the RAWG reviewed all comments and commissioned additional work from external consultants to confirm that the approach outlined in specific areas of the supplements was correct. The supplements were published in Q2 2008.

## 5. CODE SUPPLEMENTS CONTENT

### *Scope*

The code supplements[16, 17] provide a recommended framework for carrying out an assessment of the acute safety risks associated with major accident hazard pipelines containing flammable substances. The supplements are applicable to buried pipelines on land, and do not cover environmental risks.

The principles of the supplements are based on best practice for the quantified risk analysis of new pipelines and existing pipelines. This 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.

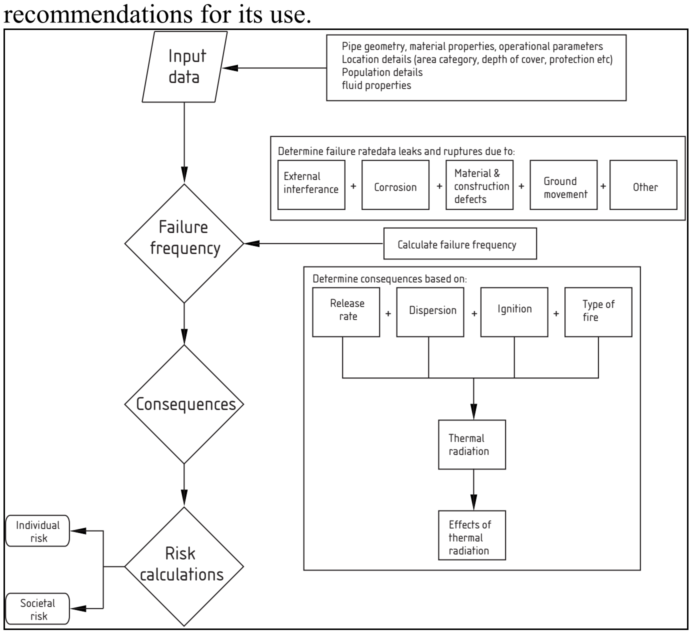


**Figure 2: Risk calculation flowchart**

As with any risk assessment, judgement must be employed by the risk assessor at all stages of the assessment. The supplements are 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 should be able to justify every key assumption made in the assessment and should document these assumptions as part of the assessment.

### *Applicable Substances*

Dangerous fluids are defined in PSR 96 and include those which are flammable in air and either transported as a gas above 7 barg or as a liquid with a boiling point below 5°C. In the UK, this means:

- Natural gas;
- Ethylene;
- Spiked crude;
- Ethane, propylene, LPG, etc.; and,
- NGL.

Currently gasoline is not defined as a dangerous fluid, although HSE has stated following the Buncefield incident[18], gasoline will be included in an amended PSR currently planned to be published in 2008. The supplements do not include guidance for the risk from toxic fluids but the best practice principles presented should apply to the assessment of these risks.

### *Pipeline Failure Modes*

Failure of a high pressure pipeline can be either as a leak or a rupture. A leak is defined as fluid loss through a stable defect and a rupture is defined as fluid loss through a defect which extends during failure, so that the release area is greater than or equal to the pipeline diameter.

Leaks can vary from pinholes up to hole sizes which represent unstable defects. In determining the applicable hole sizes, the effective release area of sub-critical defects in a specific pipeline should be taken into account.

### *Event Trees*

The event tree for releases of natural gas from the IGE/TD/1 supplement is shown in Figure 3.

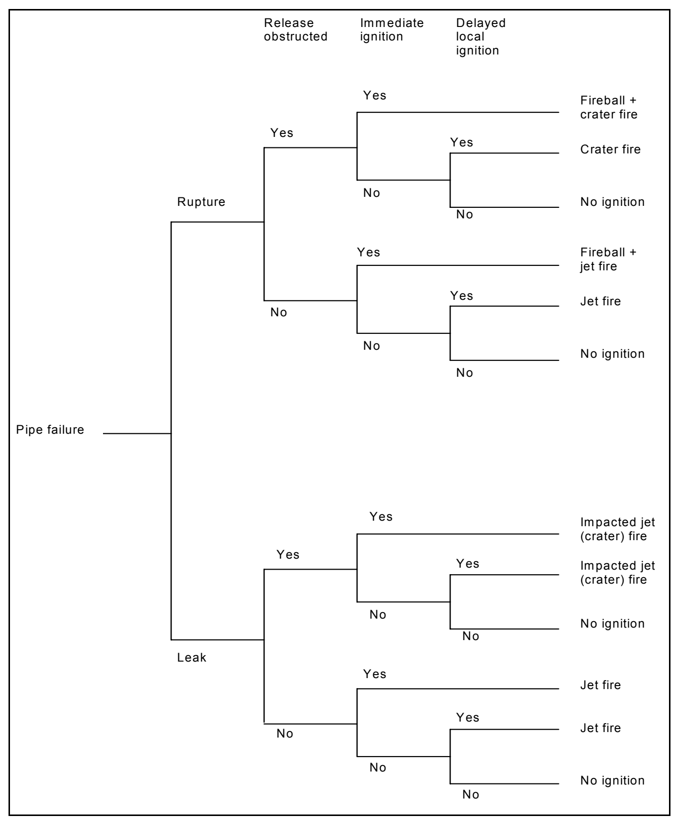


**Figure 3: Event Tree for Natural Gas releases**

Event trees for liquids and for all gases, including those heavier than air, are presented in the supplement to PD 8010[17].

### *Operational Fault and Failure Data*

The two code supplements recommend the use of recognised published operational data sources[19, 20, 21] or the use of predictive models validated using such data.

Pipeline failure frequencies derived from UK data collected since 1962 are shown in Table 2.

**Table 2: Failure Rates for UK Pipelines based on UKOPA data (per 1000 kmyears)**

| Damage Mechanism | Pinhole | Hole | Rupture | Total |
|---|---|---|---|---|
| 3rd Party Interference | 0.006 | 0.040 | 0.011 | 0.057 |
| External Corrosion | 0.035 | 0.009 | 0.002 | 0.046 |
| Internal Corrosion | 0.003 | 0.000 | 0.000 | 0.003 |
| Material & Construction | 0.063 | 0.013 | 0.000 | 0.076 |
| Ground Movement | 0.003 | 0.004 | 0.002 | 0.009 |
| Other | 0.052 | 0.019 | 0.002 | 0.073 |
| **TOTAL** | **0.162** | **0.085** | **0.017** | **0.264** |

#### Corrosion

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 including:

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

For pipelines commissioned pre-1980, it is recommended that the corrosion rates in Table 2 should be applied unless corrosion control procedures have been applied.

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

#### Material & Construction Defects

Failure frequency due to material and construction defects in the UK is dependent upon the year of construction and hence the age and associated design and construction standards, in particular the material selection controls and welding inspection standards applied. These standards 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. The UKOPA data indicates that material and construction failures occur as leaks, and that no ruptures have been recorded to date.

#### Ground Movement

For most pipelines in the UK, failures due to ground movement are unlikely as the terrain is generally not susceptible to natural ground movement. Based on a detailed assessment of pipeline failure frequency in the UK, it is recommended that a background rupture failure rate for ground movement of $2.1 \times 10^{-4}$ per 1000 kmyears is applicable to all UK major accident hazard pipelines.

### *Failure Frequency Prediction – 3rd Party Damage*

UK and European operational data regarding failures from 3rd party damage is not large enough to allow comparison with a set of specific pipeline operating parameters, especially for modern pipeline steels for which there is currently limited operating experience. Therefore, it is usually necessary to predict the pipeline failure frequency for a specific pipeline rather than to derive it from incident statistics.

The UKOPA recommended tool for predicting failure frequencies for 3rd party damage is FFREQ[22, 23] which has been used in pipeline QRA for 25 years. However, as this model is not generally available, reduction factors and generic failure frequency curves, as well as a range of standard FFREQ results are included in the supplements.

#### Generic Failure Frequency Curves

A generic pipeline failure frequency curve which has been 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 grade X65. The curve has been generated using a recreation of the original dent-gouge model[15] and is shown in Figure 4 below.

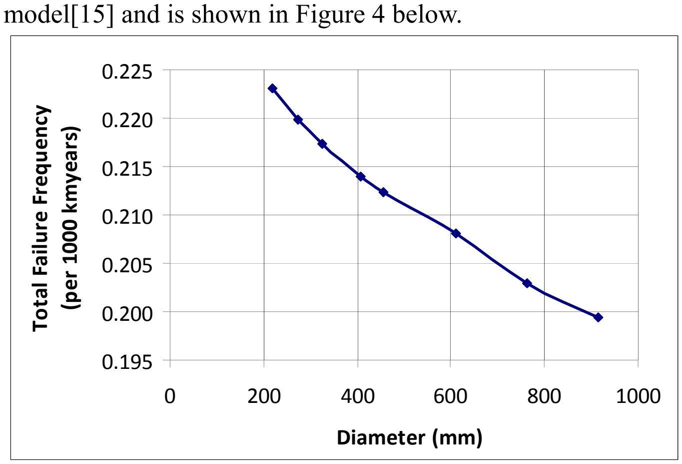


**Figure 4: Generic Failure Frequency Curve for Estimation of Total Failure Frequency due to External Interference**

## Failure Frequency Reduction Factors

To allow the estimation of site-specific pipeline failure frequencies for external interference, factors for design factor and wall thickness have been derived from comprehensive parametric studies[24]. These studies use models which describe the failure of a pipeline due to gouge and dent-gouge damage[15, 25]. These factors should be applied to a nominal failure frequency which is dependent on pipeline diameter.

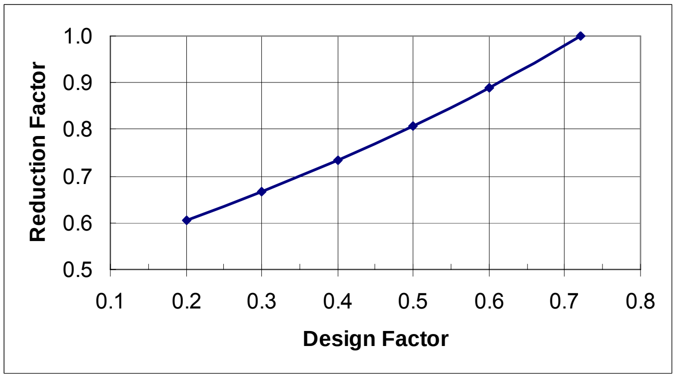


**Figure 5: Reduction in External Interference Failure Frequency due to Design Factor**

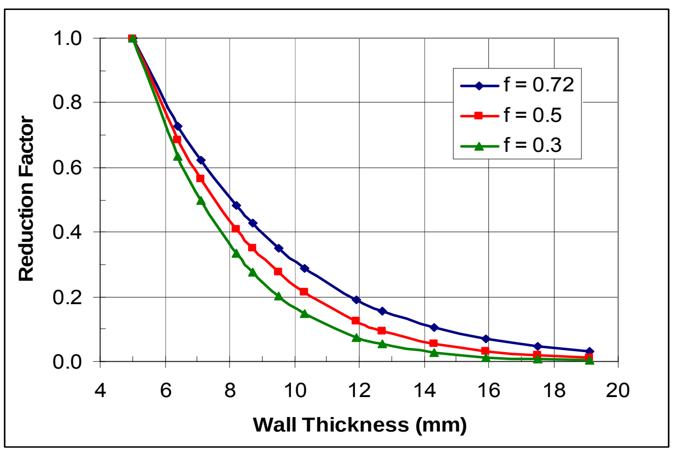


**Figure 6: Reduction in External Interference Failure Frequency due to Wall Thickness**

The reduction factors are based on conservative interpretation of the parametric study results. They may be applied separately to modify existing risk assessment results (i.e. to take into account, actual or proposed, local changes in wall thickness), or they may be used to estimate the failure frequency in screening assessments, using both factors in conjunction with the generic failure frequency curve as an alternative to more complex structural reliability based methods.

As these factors are derived from parametric studies, they are only applicable for the range of the parametric study.

**Table 3: Applicability Range for Design Factor and Wall Thickness Reduction Factors**

| Parameter | Applicability Range |
|---|---|
| Design Factor | ≤0.72 |
| Wall Thickness | ≥5 mm |
| Material Grade | ≤X65 |
| Diameter | 219.1 – 914.4 mm |
| Charpy Energy (Average) | ≥24J |

## Use of Reduction Factors

To estimate the total failure frequency (TFF) for a given pipeline, the generic failure frequency (GFF) for the correct diameter is taken from Figure 4, the reduction factor for design factor ($RF_{df}$) is taken from Figure 5 and the reduction factor for wall thickness ($RF_{wt}$) is taken from Figure 6 and combined, as shown below and in Table 4:

$$TFF = GFF \times RF_{df} \times RF_{wt}$$

**Table 4: Example Estimated Total Failure Frequency Calculations**

| Example | 1 | 2 | 3 |
|---|---|---|---|
| **Diameter (mm)** | 219.1 | 609.0 | 914.4 |
| **Wall Thickness (mm)** | 5.6 | 7.9 | 9.52 |
| **Design Factor** | 0.5 | 0.5 | 0.5 |
| **Generic Total Failure Frequency (per 1000kmyrs)** | 0.223 | 0.208 | 0.199 |
| **Design Factor Reduction Factor** | 0.67 | 0.5 | 0.81 |
| **Wall Thickness Reduction Factor** | 0.87 | 0.81 | 0.34 |
| **Estimated Total Failure Frequency (per 1000kmyrs)** | 0.130 | 0.084 | 0.055 |
| **Comparison with FFREQ Prediction (per 1000kmyrs)** | 0.076 | 0.061 | 0.043 |

The use of the generic failure frequency curve and the reduction factors will result in a conservative estimate of total failure frequency compared to the pipeline specific FFREQ predictions. This total failure frequency should be suitably split between leaks and ruptures taking into account wall thickness and design factor.

FFREQ calculations for a range of specific pipelines are also included in the supplements to provide more accurate estimates of leak and rupture rates due to 3rd party interference and allow any developed prediction methodology to be benchmarked. Details of the UKOPA recommended prediction methodology can be found in [25].

### *Risk Mitigation Measures*

Guidance is also given on, both the installation of and the level of risk reduction of, the following risk mitigation measures:

- Installation of concrete slabs[26];
- Increased surveillance levels; and,
- Increased depth of cover[27].

**Table 5: Reduction Factors for Concrete Slabbing**

| Mitigation Measure | Reduction Factor |
|---|---|
| Concrete slab | 0.16 |
| Concrete slab plus visible warning | 0.05 |

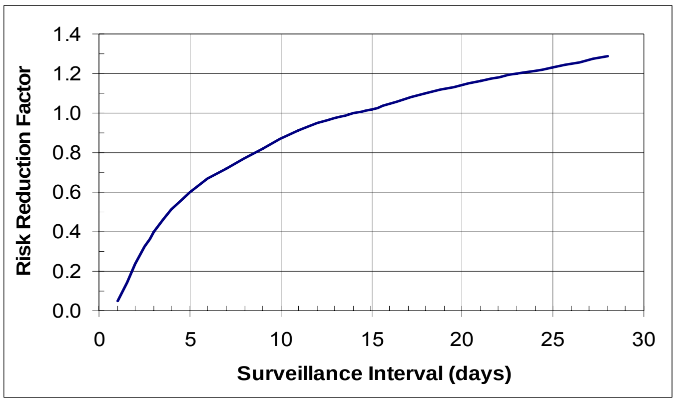


**Figure 7: Reduction in External Interference Failure Frequency due to Surveillance Frequency**

The reduction factor for surveillance frequency has derived from the results of studies carried out by UKOPA relating data on the incidence of infringement upon the pipeline route to data on the incidence of damage.

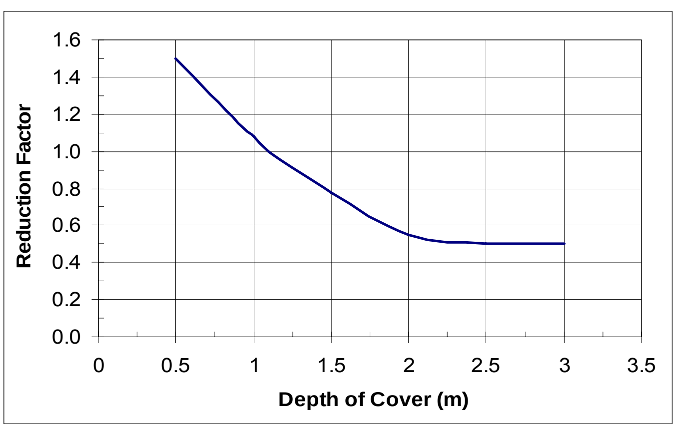


**Figure 8: Reduction in External Interference Failure Frequency due to Depth of Cover**

Use of the depth of cover reduction factor is based on the operator confirming at regular intervals that the additional depth of cover claimed as mitigation has not been eroded.

### *Consequence Assessment*

The code supplements provide guidance on key aspects of the assessment of consequences following the release of any pipeline contents:

- Calculation of release flow rate;
- Determination of ignition probability;
- Calculation of thermal radiation; and,
- Quantification of the effects of thermal radiation on the surrounding population.

## Product Release Rate

For ruptures, the outflow as a function of time should be calculated taking into account the failure location, upstream and downstream boundary conditions and any response to the failure. For liquid pipelines, the release rate for anything greater than a small hole ( > 50mm diameter) is usually dictated by the maximum pumping rate. The amount released is dependent on the time taken to identify that the pipeline is leaking and stop the pumps, depressurisation of the pipeline and drain-down of adjacent sections.

Special care needs to be taken for calculating the two-phase release or a flashing liquid. Outflow from holes should be calculated using conventional sharp edged orifice equations with a suitable discharge coefficient and can usually be taken as steady state.

## Ignition Probability

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 30s, and delayed ignition occurs after 30s. Generic, product-specific values for ignition probability can be obtained from data from historical incidents[12, 20, 21, 28] and the various ignition possibilities such as immediate, delayed and obstructed or unobstructed, can be drawn out logically on an event tree to obtain overall probabilities of ignition.

The probability of occurrence of a crater or jet fire is dependent on assumptions made about the degree of obstruction of the escaping fluid and the sources of delayed ignition close to the release point. Flash fires occur when a plume of unignited heavier-than-air gas from an obstructed release 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. A vapour cloud can drift further in night-time conditions than day time. 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 usually considered to be low, depending on the extent of population and distribution of ignition sources in the vicinity of a pipeline.

Spray fires occur when a flammable liquid is released at high velocity through a hole in a pipeline. Spray fires are usually modelled assuming the plume of evaporating vapour drifts downwind in a similar way to heavier-than-air gases.

## Calculation of Thermal Radiation

Thermal radiation is calculated from the energy of the burning material using either the view factor method[28], which assumes a surface emissive power for the flame, or the point source method[28], which assumes that all the energy is emitted from several point sources. The thermal radiation from a fireball is usually calculated using the view factor method.

For a rupture release of a gaseous fluid, it is normally assumed that the two ends of the failed pipeline remain aligned in the crater and the jets of fluid interact. For small diameter pipelines and for failures close to a bend, this assumption may be non-conservative and the risk assessment should take into account the sensitivity of the location assessed to a directional release. Crater fires produce higher levels of radiation at ground level than a free jet fire which may have a substantial lift-off distance before the flame appears.

The effects of wind on fire tilt and maximum radiation at ground level should be taken into account.

## Thermal Radiation Effects

Fatal injury effects are typically assumed for cases where people in the open or in buildings are located within the flame envelope for a fireball, crater, spray or jet fire.

The thermal radiation effect at distances from the failure, calculated as the radiation dose, should be summed through the complete fire event to determine the effect on people and property. This is calculated in terms of the piloted ignition distance for buildings, the escape distance for people out of doors, and the distance for which escape to safe shelter is possible.

It is generally assumed that all persons out doors and indoors within the piloted ignition distance try to escape and to calculate the safe escape distance, a number of factors should be taken into account, including:

- the escape speed which should reflect the potential difficulty in escaping directly away from the fire and the terrain to be crossed;
- the location and types of buildings; and
- the varying population indoors and out doors throughout the day night.

The thermal radiation dose, defined as $I^{4/3}.t$, received by an escaping person can be calculated by integrating the incident thermal radiation flux, I, as it varies with time, t, and the distance from the pipeline.

The standard assumption in the UK is to use 1800 thermal dose units (tdu) as a fatality criterion for standard adult populations. 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 the fire. For sensitive developments, the 1 % lethality dose of 1050 tdu is commonly used. This level is equivalent to the HSE dangerous dose.

### *Individual & Societal Risk Assessment*

Individual risk is the probability of an individual at a specific location becoming a casualty from a specific hazard. The individual risk from pipelines is typically taken for a person permanently resident and presented as the risk levels along a transect perpendicular to the pipeline. The risk from the various failure scenarios should be combined.

In the UK, acceptable individual risk levels have been set by the safety regulator, the Health & Safety Executive (HSE) as shown in the diagram in Figure 9[29, 30, 31].

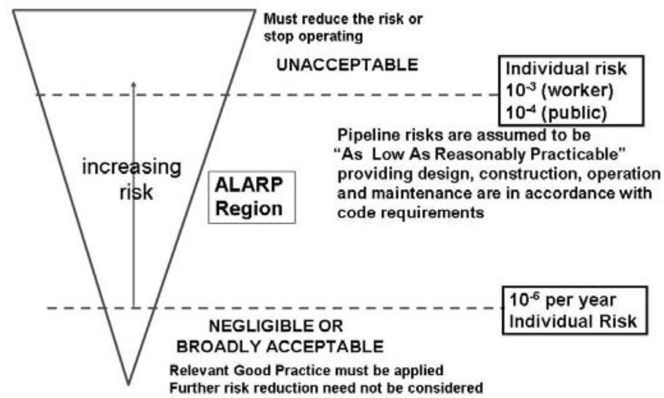


**Figure 9: UK HSE Individual Risk Criteria**

Societal risk is defined as the relationship between the frequency of an incident and the number of casualties that may result and is typically presented as a graph of the frequency F of N or more casualties per year versus N, commonly referred to as an FN curve. Societal risk assessments can be generic, with an assumed constant population density adjacent to the pipeline, or site-specific in which the layout of the site and population distribution around the site and throughout the day is taken into account.

IGE/TD/1 already includes a sample FN criterion, see Figure 10 and a similar curve has been developed for PD 8010 and pipelines carrying fluids other than natural gas.

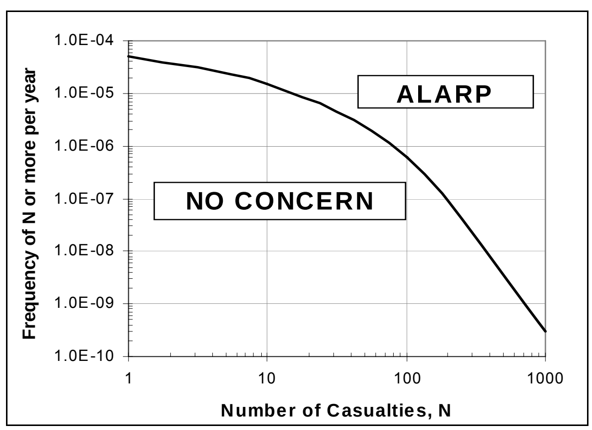


**Figure 10: IGE/TD/1 Sample FN Criterion**

### *Guidance on UK HSE Methodology for Land Use Planning*

The supplements include an appendix that summarises the current UK land use planning advice system, as outlined above, and provides details on HSE assessment methodology. Accordingly pipeline operators can determine the effect on the consultation zones of local pipeline properties or proposed risk mitigation and hence identify if a proposed development is likely to be advised against.

### *Example Site-Specific Assessment*

An example of a site-specific assessment is included, to illustrate some of the QRA concepts, in the supplements. The case concerns a planning application for 38 houses that lie in the middle and outer zone from a pipeline, see Figure 11.

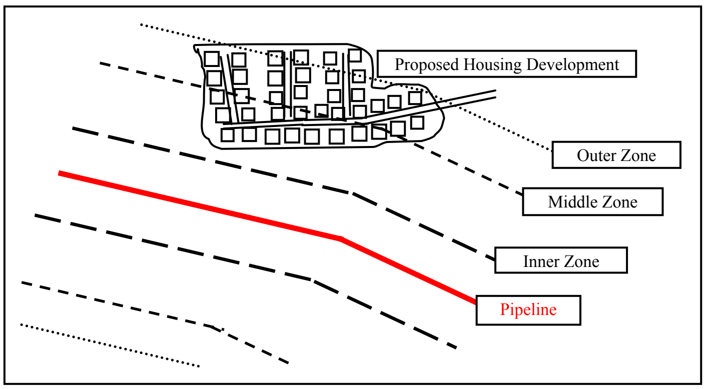


**Figure 11: Example Site Specific Assessment**

The planning authority follows the HSE PADHI guidance, identifies that the HSE would advise against and informs the developer that planning permission will be refused on safety grounds.

The failure frequency and consequence calculations are outlined, leading to calculation of individual risk and hence distance to the consultation zone boundaries. The example then shows the reduction in these distances related to different mitigation measures, leading to acceptance of the development and the granting of planning permission.

## 6. CONCLUSIONS

The development of new QRA supplements to the UK pipeline design codes has been described. The supplements provide guidance on best practice for pipeline risk assessment in the UK, and have been developed to support the increasing use of QRA to evaluate and assess the risks posed by pipelines transporting hazardous fluids.

The supplements provide specific guidance on the application of QRA to assess the risks to new developments planned in the vicinity of existing pipelines, and the evaluation of the reduction in risk which can be achieved through the use of mitigation measures. In this respect, the primary aim of the supplements is to promote consistency in the use of QRA and decisions made based on the results obtained. The supplements achieve this through the inclusion of:

i) inclusion of guidance on the selection of input data, relevant assumptions and the application of assessment criteria for site specific risk assessments, and

ii) presentation of quantified examples which demonstrate the application of the guidance.

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