NEW UK PIPELINE RISK ASSESSMENT CODES – IGEM TD/2 AND PD 8010 PART 3

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The United Kingdom Onshore Pipeline Operators Association, UKOPA was formed in 1997 by UK pipeline operators to provide a forum for representing pipeline operators interests in all matters related to the safe management of pipelines. One of the key requirements is ensuring the pipeline design and operating codes represent best practice, and that there is a common view amongst operators and the regulators in terms of compliance with these codes.

Major hazard cross country pipelines are laid in 3rd party land with an operational life typically greater than 50 years. During this time, the land adjacent to a pipeline is subject to change, and developments are likely to occur near the pipeline route. This often means there is an increase in residential or working population near the pipeline, and as a result the pipeline may become non-compliant with code requirements which originally routed the pipeline safely away from populated areas.

To address this situation, land use planning is applied so that the safety of, and risk to developments in the vicinity of major hazard pipelines are assessed at the planning stage. The Health & Safety Executive (HSE) are the statutory consultees in this process, and they set risk-based consultation zones around such pipelines, within which the risks to people and developments must be assessed and taken into account when planning authorities consider new planning applications. For most cases, standard decision tables are applied by the planning authority from the HSE document PADHI (Planning Advice for Developments near Hazardous Installations), but for borderline or difficult cases, site specific quantified risk assessments (QRAs) are applied to obtain risk levels, and to assess possible mitigation measures to reduce risks.

Quantified 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 the new codes IGEM/TD/2 and PD 8010 Part 3, in order to provide authoritative and accepted guidance on the risk analysis of site specific pipeline details, for example increased wall thickness, pipeline protection (such as slabbing) depth of cover, damage type and failure mode, and the impact of mitigation measures which could be applied as part of the development. The availability of this codified advice helps to create a standard and consistent approach, and reduces the potential for disagreement between stakeholders with respect to the acceptability of proposed developments.

The new codes are now complete and were published in early 2009.

This paper describes the guidance given in the new codes in relation to prediction of pipeline failure frequency, consequence modelling, application of risk criteria and implementation of risk mitigation, and summarises the assessment examples provided.

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 Europe, Scotia Gas Networks, Shell, Total, Unipen, and 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
Pipelines are designed, built, operated and managed in accordance with the goal-setting Pipeline Safety Regulations 1996 (PSR 96) [HMSO, SI 825, 1996] which set out duties to ensure that risk levels from pipelines are "as low as reasonably practicable" (ALARP). The guidance to these regulations 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.

In the 1960s, before the discovery of North Sea gas and subsequent development of long distance gas transmission pipelines, UK pipeline codes [Institution of Gas Engineers, 2001, British Standards Institution, 2004] were simple interpretations of American ASME B31 codes based on North American experience.

However they were subsequently 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.

In addition, the concept and use of a 'building proximity distance' (BPD) was adopted for the gas code IGE/TD/1 [Institution of Gas Engineers, 2001], this being the minimum separation distance between occupied buildings and the pipeline, used when the pipeline route is first selected. The BPD is calculated from the pressure and diameter of a pipeline, and presented as charts in the existing codes.

For non-natural gas pipelines, the British Standard BS 8010 was developed in the 1980s, and high hazard substances such as hydrogen, LPG and ethylene (and including natural gas) were labelled Category E substances. These substances have a Minimum Distance to Occupied Buildings (MDOB) specified based on substance factors given in the code. BS EN 14161 (based on European Codes) superseded BS 8010 which was withdrawn in 2004, and the Published Document PD 8010 [British Standards Institution, 2004] was published by BSI in its place.

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 (i.e. within the BPD). This can result in the pipeline becoming non-compliant with the original code requirements.

The 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, QRA is usually applied to assess whether the risk is acceptable.

Where risk levels are considered to be unacceptable, risk mitigation measures may 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 the section of pipeline in thicker wall and so reducing the BPD, or diversion of the pipeline away from the populated area. QRA is used to assess the effectiveness of mitigation and to select the most appropriate measure in a specific situation. Guidance in the new codes aims to ensure consistent assessment of risk mitigation measures in terms of the risk reduction achieved.

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 several factors such as selection of physical layout, scale of the development, aesthetics, landscape, economics, and in particular, public safety and environmental impact.

The Control of Industrial Major Hazard (CIMAH) Regulations 1984 established a "Consultation Zone" around major hazard sites within which Local Planning Authorities were required to seek the advice of the Health & Safety Executive (HSE) concerning new developments. Planning authorities were not obliged to follow this advice, but the HSE had the right to "call in" the planning application so that it would be considered by an independent planning inspector, and a public inquiry. 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 currently defined in 3 levels:

- the inner zone (IZ), which is immediately adjacent to the pipeline, equivalent to an individual risk level of 10^{-5} per year
- the middle zone (MZ), which applies to significant developments, equivalent to an individual risk level of 10^{-6} per year, and
- the outer zone (OZ), also known as the Consultation Distance (CD), equivalent to an individual risk level of 3×10^{-7} per year, which applies to vulnerable or very large populations.

These zones are shown diagrammatically for a pipeline in Figure 1.

PLANNING ADVICE FOR DEVELOPMENTS NEAR HAZARDOUS INSTALLATIONS

Originally HSE guidance for developments inside the land use planning zones resulted in many marginal planning developments being referred back to the HSE for detailed assessment. Subsequently HSE produced an improved decision matrix and guidance document called Planning Advice for Developments near Hazardous Installations (PADHI) [Health and Safety Executive, 2004].
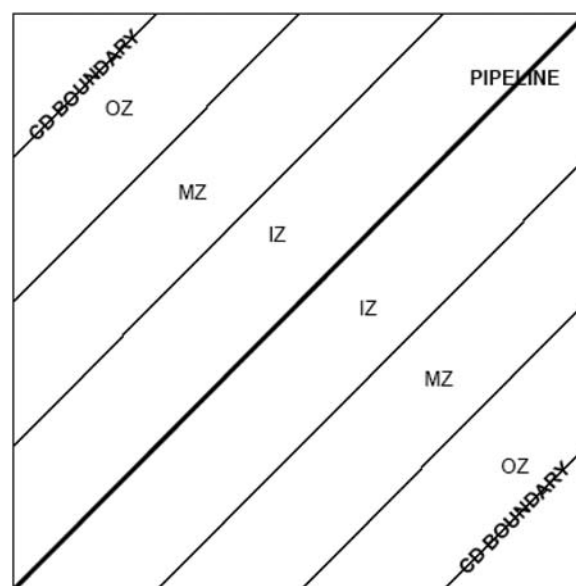

Figure 1. Consultation distance and zones

The planning authority will usually refuse planning permission for a new development if PADHI indicates that the risks posed by the hazardous pipeline are too high, and only in a few cases will the development be referred to the HSE for a more detailed site-specific assessment.

The PADHI process uses risk-based inner, middle and outer zones combined with the sensitivity level of the 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. The HSE use this information to calculate risk-based distances to the zone boundaries from the pipeline, defining the levels of individual risk at each zone boundary, 10^{-5} per year, 10^{-6} per year, and 3×10^{-7} per year. The individual risk is calculated by HSE for the average householder by applying a dangerous dose casualty criterion for thermal radiation.

Maximum risks from major hazard pipelines are usually lower than the 1×10^{-5} per year inner zone boundary, so in theory, they would not have an inner zone. However, HSE apply the code-based Building Proximity Distance to natural gas pipelines as the inner zone, and the fireball radius to non-natural gas pipelines.

The individual risk is calculated by HSE for the average householder by applying a dangerous dose casualty criterion for thermal radiation.

PADHI DECISION MATRIX

The PADHI process uses two inputs to a decision matrix to generate an assessment decision: the LUP zone (inner, middle or outer) in which the proposed development is located, and the 'sensitivity level' of the proposed development, which is derived from an HSE categorisation system of "development types". Development types are used as a direct indicator of the sensitivity level of the population at the proposed development. The sensitivity levels allow progressively more severe restrictions to be imposed as the sensitivity of the proposed development increases.

The location and sensitivity level of the development are then used to obtain the public safety planning advice from the PADHI decision matrix, which results in "Advise Against" (AA) or "Do Not Advise Against" (DNAA).

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 need to be standardised where possible.

DEVELOPMENT OF PIPELINE QRA

IGE/TD/1 Edition 4 requires the operator to carry out a regular 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 (i.e. population increases) 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 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 to reduce risks from hazardous pipelines was very high compared to the reduction in the predicted risk levels, so expenditure was disproportionate with the benefit obtained.

However, 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 increased availability and power of computers led to the British Gas knowledge-based risk assessment methodology package TRANSPIRE [Hopkins, H.F., 1993] (which has been subsequently developed to the present day as PIPESAFE [Acton, M.R., 1998]).

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

The use of QRA for the safety evaluation of pipelines is now accepted practice [Corder, I., 1995], 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, and results can be highly dependent upon the input data, assumptions and approach taken.

DEVELOPMENT OF THE NEW RISK CODES

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.

IGE/TD/1 Edition 4 and PD 8010 (2004) already include the possibility of using QRA for initial pipeline routing or to justify code infringements, and they also include some general guidance on the use of QRA. However UKOPA considered that additional specific guidance on input data, assumptions and assessment criteria is required and so, in 2005, it decided to initiate a project to develop risk assessment supplements for the two pipeline codes. Subsequently these code supplements have been

adopted as separate code documents, IGEM/TD/2 and PD 8010 Part 3.

The primary purpose of these was to provide authoritative and accepted guidance on the risk analysis of site-specific pipeline details, for example increased wall thickness, pipeline protection (such as slabbing), depth of cover, damage type and failure mode, and additional risk mitigation measures, which could be applied as part of the development.

The availability of this codified advice aims to 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 based on industry best practice although it does not define a specific model or computer software.

The codes 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 new codes was correct. The codes were published in early 2009.

CONTENT OF THE NEW CODES
SCOPE
The codes provide a recommended framework for carrying out an assessment of the acute safety risks associated with major accident hazard pipelines containing flammable substances. The new codes are applicable to buried pipelines on land, and do not cover environmental risks.

The principles in the codes are based on best practice for the quantified risk analysis of new pipelines and existing pipelines. They are not intended to replace or duplicate existing risk analysis methodology, but to support the application of the methodology and provide recommendations for its use. The overall process is shown in the Risk Assessment Flowchart in Figure 2.

As with any risk assessment, the risk assessor must employ judgement at all stages of the assessment, and the new codes are intended to support the application of this expert judgement. The final responsibility for the risk assessment lies with the assessor, and it is essential that every key assumption should be justified and documented 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
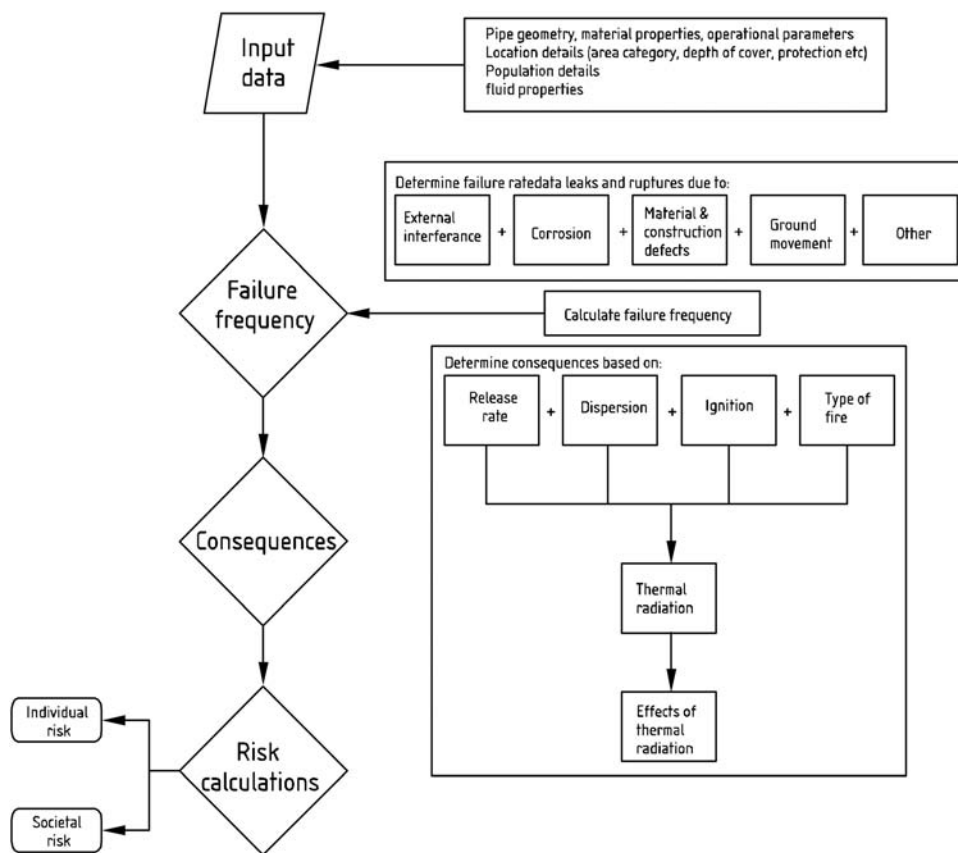

Figure 2. Risk calculation flowchart

above 7 barg or as a liquid with a boiling point below 5°C. This applies to the following major hazard pipelines currently in operation in the UK: natural gas, ethylene, spiked crude, ethane, propylene, LPG, and NGL.

Currently gasoline is not defined as a dangerous fluid, although HSE has stated following the Buncefield incident, gasoline will be included in an amendments to PSR 96, currently planned to be published in 2009–2010. The new codes 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.

EVENT TREES
Event trees for releases of natural gas and other substances are shown in the new codes.

OPERATIONAL FAULT AND FAILURE DATA
The two new codes recommend the use of recognised published operational data sources [Arunakumar, G., 2007, Davis, P.M., 2007, EGIG, 2005] or the use of predictive models validated using such data. Pipeline failure frequencies derived from UK data collected since 1962 are shown in Table 1. UKOPA collects and publishes the failure rate data on its website every 2 years.

CORROSION
Corrosion failures can occur due to internal or external corrosion. However for UK major hazard pipelines carrying clean fluids, internal corrosion is not an issue, and only external corrosion is considered as causing a risk of failure.

The failure frequency due to corrosion is dependent upon the year of construction and hence the age and applicable coating, corrosion protection design standards and corrosion control procedures. For pipelines commissioned

pre-1980, recommended corrosion failure rates are given in the new codes and for pipelines commissioned after 1980, and with corrosion control procedures applied, the corrosion failure frequency rate is reduced by a factor of 10. The data shows that to date there is no operational experience of rupture failure due to corrosion in the UK.

MATERIAL & CONSTRUCTION DEFECTS
Material and construction defects are grouped together as "mechanical" failure associated with weaknesses in the steel pipe wall due to manufacturing or welding defects, and dents or other weaknesses dating from the original construction activities. Failure frequency due to material and construction defects 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 is reduced 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 conservative background rupture failure rate for ground movement of 2.1×10^{-4} per 1000 km.years is applicable to all UK major accident hazard pipelines.

FAILURE FREQUENCY PREDICTION – 3RD PARTY DAMAGE
Pipeline failure due to external interference (usually called 3rd party damage) is the most likely cause. Unauthorised excavations cause numerous pipeline damage incidents, some resulting in a loss of fluid from the pipeline.

However, the number of 3rd party failures from UK and European operational databases is not sufficiently comprehensive to allow historical data to be used for all different combinations of pipeline operating parameters, especially for modern pipeline steels for which there is currently limited operating experience. Therefore, it is necessary to predict the pipeline failure frequency for a specific pipeline rather than to derive it from incident statistics. Such models use detailed fracture mechanics based on known pipeline parameters to predict the resistance and therefore the failure rate of a specific pipeline design.

The UKOPA recommended tool for predicting failure frequencies for 3rd party damage is a program originally developed for British Gas called FFREQ [Corder, I., 1995, Corder, I., 1992] which has been used in pipeline QRA for 25 years. However, as this model is not generally available,

Table 1. Failure rates for UK pipelines based on UKOPA data (per 1000 km.years)

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

reduction factors and generic failure frequency curves, as well as a range of standard FFREQ results are included in the new codes.

GENERIC FAILURE FREQUENCY CURVES

A generic pipeline failure frequency curve is presented 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 steel grade X65. Design factor is a measure of the stress level in a pipe, and is calculated from the pipeline diameter, pipe wall thickness, maximum operating pressure, and steel maximum yield stress (SMYS). Pipelines in the UK are mostly designed to a maximum of 0.72. The curve has been generated using a re-creation of the original dent-gouge model [Corder, I., 1995] and is shown in Figure 3.

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 [Cosham, A., 2008]. These studies use models which describe the failure of a pipeline due to gouge and dent-gouge damage [Corder, I., 1995, Lyons, C., 2008]. These factors are applied to a nominal failure frequency which is dependent on pipeline diameter. Figure 4 shows the reduction in external interference failure frequency due to design factor, and Figure 5 shows the reduction due to wall thickness.

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 3, the reduction factor for design factor (RF_{df}) is taken from Figure 4 and the reduction factor for wall thickness (RF_{wt}) is taken from Figure 5 and combined, as shown below:
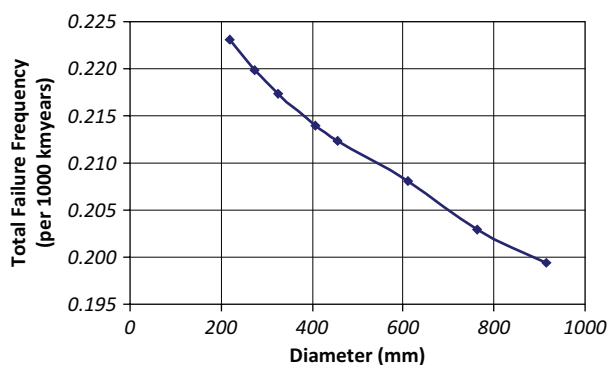
$$TFF = GFF \times RF_{df} \times RF_{wt}$$

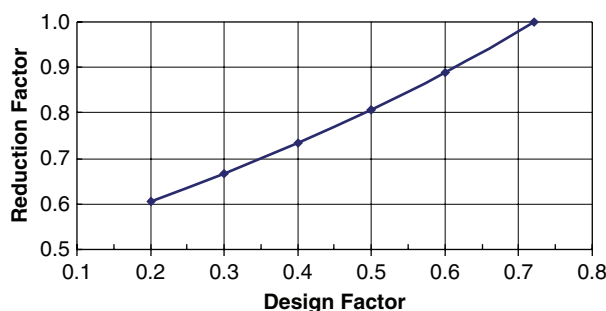**Figure 3.** Generic failure frequency curve for estimation of total failure frequency due to external interference

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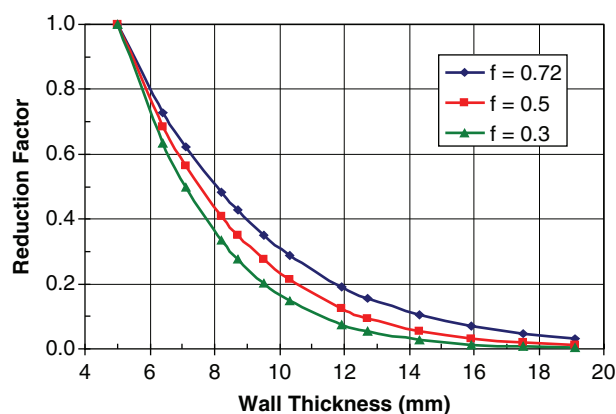

Figure 5. Reduction in external interference failure frequency due to wall thickness

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 new codes 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 [Lyons, C., 2008].

RISK MITIGATION MEASURES

Guidance is also given on both the installation of, and the level of risk reduction for installation of concrete slabs, increased surveillance levels, and increased depth of cover [HSE, 2001].

Concrete slabbing reduces the possibility of external interference by warning an excavator driver that there is something below the concrete slab. However the effectiveness of the slabbing is considerably increased if there is

Table 2. Reduction factors for concrete slabbing

Mitigation measure	Reduction factor
Concrete slab	0.16
Concrete slab plus visible warning	0.05

brightly-coloured marker tape located above the concrete slabbing. Table 2 shows the reduction factors for concrete slabbing.

Current UK pipeline codes require most pipeline routes to be surveyed every 2 weeks. This allows the operator to check that nothing untoward is occurring along the pipeline route, including unauthorised excavations, earth movements or construction work. This is usually carried out by over-flying the route, often by helicopter. More frequent route surveillance is more likely to detect and stop such works before the pipeline is damaged. Figure 6 shows the reduction in external interference failure frequency due to increasing the surveillance frequency. This reduction factor has been derived from the results of studies carried out by UKOPA relating data on infringement frequency to damage frequency.

Standard depth of cover for most pipelines is between 0.9 and 1.1 metres. Increased depth of cover reduces the probability of an excavation damaging a pipeline, and historical data has been recorded for incident frequency for different depths of cover. Figure 7 shows the reduction in external interference failure frequency due to depth of cover.

CONSEQUENCE ASSESSMENT
The new codes 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.
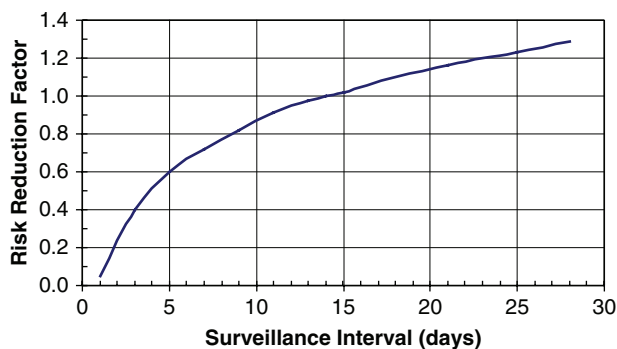
Figure 6. Reduction in external interference failure frequency due to surveillance frequency
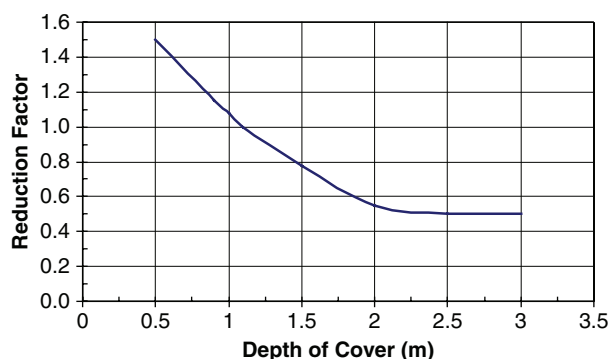
Figure 7. Reduction in external interference failure frequency due to depth of cover

PRODUCT RELEASE RATE
For ruptures, the outflow as a function of time is 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 (>50 mm 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. Outflow from holes is 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 30 s, and delayed ignition occurs after 30 s. Generic, product-specific values for ignition probability can be obtained from data from historical incidents [Davis, P.M., 2007, EGIG, 2005, Arunakumar, G., 2007] 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.

CALCULATION OF THERMAL RADIATION
Thermal radiation from fireballs, crater fires and jet fires is calculated from the energy of the burning material using either the view factor method [Mannan, S. eds., 2005], which assumes a surface emissive power for the flame, or the point source method [Mannan, S. eds., 2005], which also assumes that all the energy is emitted from several point sources.

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 long duration fireball, crater, or jet fire. The thermal radiation effect at distances from the failure, calculated as the radiation dose, is 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 outdoors and indoors within the piloted ignition distance try to escape from the continuing jet fire, and therefore the safe escape distance is calculated.

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

The standard assumption 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. For land use planning assessments and setting land use planning zones, HSE use the "dangerous dose" level of 1000 tdu whereas pipeline operators usually use 1800 tdu when carrying out societal risk assessments.

INDIVIDUAL & SOCIETAL RISK ASSESSMENT

The individual risk from pipelines is typically taken for a person permanently resident next to the pipeline and presented as the risk levels along a transect perpendicular to the pipeline. Acceptable, ALARP, and unacceptable risk limits are published by HSE [HMSO, 2001].
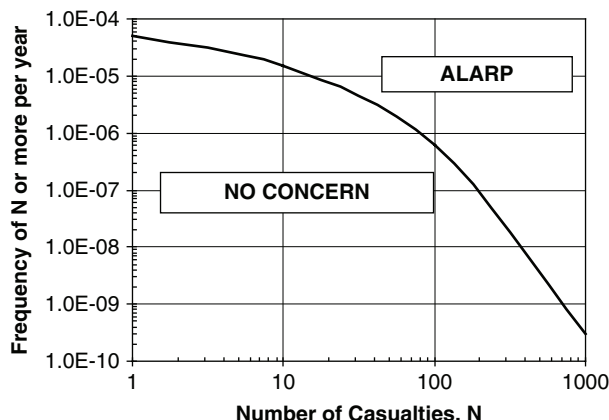

Figure 8. IGE/TD/1 sample FN criterion

Societal risk is typically presented as a graph of the frequency F of N or more casualties per year versus N for a fixed length of pipeline (1 km or 1.6 km), 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 for 1.6 km of pipeline, see Figure 8, and a similar curve has been developed for PD 8010 Part 3 for pipelines carrying fluids other than natural gas, based on suggested HSE criteria applied to a fixed COMAH site.

GUIDANCE ON UK HSE METHODOLOGY FOR LAND USE PLANNING

The new codes 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
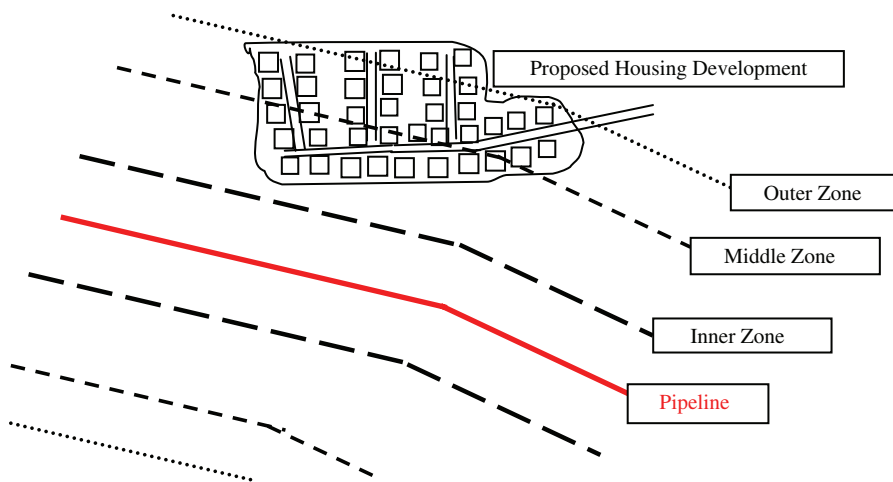

Figure 9. Example site specific assessment

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 OF A SITE-SPECIFIC ASSESSMENT

An example of a site-specific assessment is included in the new codes to illustrate some of the QRA concepts including the risk reduction effect of the mitigation methods. The case shown is typical of a possible new development and concerns a planning application for 38 houses that lie within the middle and outer zones from a high pressure gas pipeline, see Figure 9.

The planning authority follows the HSE PADHI guidance which results in Advise Against. This is because the development exceeds 30 dwellings and is therefore Sensitivity Level 3, PADHI Rule 1 Straddling Developments states that the development is considered to be in the middle zone, and the PADHI decision matrix results in Advise Against for Sensitivity Level 3 developments in the middle zone.

The failure frequency and consequence calculations are outlined, leading to calculation of individual risk. The example then shows the reduction in zone distances related to different mitigation measures, such that for some cases, the middle zone reduces such that the development is then only in the outer zone, leading to acceptance of the development and the granting of planning permission.

CONCLUSIONS

Despite extensive guidance in UK pipeline design codes on the safe routing of major hazard pipelines away from populated areas, subsequent planning developments and encroachment during the operating life of these pipelines results in the need to carry out quantified risk assessments to determine the acceptability of such developments. New risk codes have been published which 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 new codes 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 new codes is to promote consistency in the use of QRA and decisions made based on the results obtained. The new codes achieve this through the inclusion of guidance on input data, relevant assumptions and the application of assessment criteria for site specific risk assessments, and presentation of examples which demonstrate the application of the guidance.

REFERENCES

Acton, M.R., Baldwin, P.J., Baldwin, T.R., Jager, E.E.R., 1998, The Development of the PIPESAFE Risk Assessment Package for Gas Transmission Pipelines, Proceedings of the International Pipeline Conference (IPC98), ASME International.

Arunakumar, G., 2007, UKOPA Pipeline Fault Database, Pipeline Product Loss Incidents (1962–2006), 5th Report of the UKOPA Fault Database Management Group, Advantica Report 6957, Loughborough, UK, August 2007. Available from UKOPA website http://www.ukopa.co.uk/publications/pdf/UKOPA-07-0050.pdf.

British Standards Institution, 2004, Code of Practice for Pipelines – Part 1: Steel Pipelines on Land, PD 8010.

British Standards Institution, 2008, 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 containing flammables – Supplement to PD 8010-1:2004.

Corder, I., Fearnehough, G.D., and Knott, R.N., 1992, Pipeline Design Using Risk Based Criteria, Institute of Gas Engineers 129th Annual General Meeting and Spring Conference, Communication 1492, Eastbourne, UK.

Corder, I., 1995, The Application of Risk Techniques to the Design and Operation of Pipelines, C502/016/95, Proceedings of International Conference on Pressure Systems: Operation and Risk Management, Institution of Mechanical Engineers, London, October 1995, pp. 113–125.

Cosham, A., Haswell, J. and Jackson, N., 2008, Reduction Factors for Estimating the Probability of Failure of Mechanical Damage due to External Interference, IPC2008-64345, Proceedings of IPC2008, 7th International Pipeline Conference, American Society of Mechanical Engineers, September 29th to October 3rd, Calgary, Alberta, Canada, 2008.

Davis, P.M. et al, 2007, Performance of European cross-country oil pipelines. Statistical summary of reported spillages in 2005 and since 1971, Report 4/07, prepared by the CONCAWE Oil Pipelines Management Group's Special Task Force on oil pipeline spillages (OP/STF-1), CONCAWE, Brussels, May 2007.

EGIG, 2005, "Gas Pipeline Incidents 1970–2004", 6th Report of the European Gas Pipeline Incident Group, EGIG 05.R.0002, December 2005.

Health and Safety Executive, 2004, Planning advice for developments near hazardous installations (PADHI+). Available for downloading at http://www.hse.gov.uk/landuseplanning/index.htm.

HMSO SI 825, 1996, The Pipeline Safety Regulations 1996– Guidance on Regulations.

HMSO, 2001, Reducing risks, protecting people. HSE's decision-making process, HMSO, London 2001.

HSE, 2001, An assessment of measures in use for gas pipelines to mitigate against damage caused by third party activity, Contract Research Report 372/2001, prepared by WS Atkins Consultants Ltd. for the Health and Safety Executive, HMSO, London 2001.

Hopkins, H.F., Lewis, S.E. & Ramage, A.D., 1993, The Development and Application of the British Gas TRANSPIRE Pipeline Risk Assessment Package, presented to IGE Midland Section, 19th October 1993.

Institution of Gas Engineers, 2001, Steel Pipelines for High Pressure Gas Transmission, Recommendations on Transmission and Distribution Practice, IGE/TD/1 Edition 4, 2001.

Institution of Gas Engineers and Managers, 2008, Application of Pipeline Risk Assessment to Proposed Developments in the Vicinity of High Pressure Natural Gas Pipelines, IGE/TD/2 Communication 1737.

Lyons, C., Haswell, J.V., Hopkins, P., Ellis, R., Jackson, N., 2008, A Methodology for the Prediction of Pipeline Failure Frequency due to External Interference, IPC2008-64375, Proceedings of IPC2008, 7th International Pipeline Conference, American Society of Mechanical Engineers, September 29th to October 3rd, Calgary, Alberta, Canada.

Mannan, S. eds., 2005, Lees' Loss Prevention in the Process Industries, 3rd Edition, Elsevier Butterworth-Heinemann, Oxford, UK.