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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A COMPARISON OF INHERENT RISK LEVELS IN ASME B31.8 AND UK GAS PIPELINE DESIGN CODES

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

Dr. Jane Haswell
Pipeline Integrity Engineering
Newcastle upon Tyne, UK
jane.haswell@pieuk.co.uk

ABSTRACT

The approach to gas pipeline risk and integrity management in the US, involving the development of integrity management plans for High Consequence Areas (HCA), is usually qualitative, as outlined in ASME B31.8S. Depending on the engineering judgement of the assessment team this can lead to a wide variety of results making risk comparison between pipelines difficult. Qualitative risk ranking methods are popular in Europe, but quantitative risk assessment (QRA) is also used for setting acceptable risk levels and as an input to risk and integrity management planning. It is possible to use quantitative risk assessment methods to compare the levels of risk inherent in different pipeline design codes.

This paper discusses the use of pipeline quantitative risk assessment methods to analyse pipelines designed to ASME B31.8 and UK IGE/TD/1 (equivalent to PD 8010, published by BSI, for the design of gas pipelines) codes. The QRA utilises predictive models for consequence assessment, e.g. pipeline blowdown and thermal radiation effects, and failure frequency, in determining the risk levels due to an operational pipeline. The results of the analysis illustrate how the risk levels inherent in the two codes compare for different class locations & minimum housing separation distances.

The impact of code requirements on design factor, depth of burial, population density and the impact of third party activity on overall risk levels are also discussed.

1. INTRODUCTION

Risk & Gas Pipelines

Natural gas is transported at high pressure through an extensive network of pipelines throughout the world. High pressure gas is hazardous: an understanding of the risks is essential. Failure of a high pressure natural gas pipeline will result in the release of a large quantity of gas, which if ignited, will cause significant thermal radiation, resulting in fatalities and injuries to people and significant damage to property in the range affected.

Pipelines are long, linear assets which are generally located on land not controlled by the operator, to which the public may have access. In this respect pipelines present a risk to people which must be addressed by understanding and minimising the probability of failure and limiting the consequences.

Risk is generally expressed as:

Risk = Probability of Failure x Consequences of Failure.

Pipeline failure is defined as any loss of containment due to failure of the pipe wall. The generic pipeline failure modes that can occur are leaks or ruptures:

i) Stable through-wall defects give leaks.

ii) Unstable defects that grow as a result of energy in the pipe wall and that transferred from the depressurising gas give ruptures.

The main difference is the size of pipe break and therefore the volume of gas lost. Leaks may be due to a hole of any size, and typically are treated as steady-state releases with no significant reduction in internal pressure. A rupture can result in a full bore escape, in which gas escapes from both the upstream and downstream pipeline sections, resulting in a rapid depressurisation.

Risk in Pipeline Codes & Standards

The principal requirement in assuring public safety and avoiding damage to the environment or property is to reduce the potential for a major pipeline accident to occur, so the design should ensure that the probability of failure due to any cause is low.

The risks posed by hazardous pipelines are controlled by safety legislation: usually they require that all hazards affecting the pipeline with the potential to cause a major accident are identified, the risks arising are assessed and controls put in place to minimise the likelihood of an accident.

Safe management of a pipeline is the responsibility of the pipeline operator, and is usually achieved by meeting the requirements of relevant national legislation and regulations through the interpretation and application of recognised standards and codes which are relevant to the pipelines in operation.

Pipeline codes recognise the potential risks posed by gas pipelines by relating the factors which affect the probability of failure to consequences in particular areas. The purpose of codes and standards is to set a recognised baseline risk based on experience and best practice. Codes do this through:

- Ensuring the consistent application of engineering principles (e.g. design factor);
- Accurate calculation of physical parameters (e.g. wall thickness);
- Location (i.e. with respect to population);
- Methods of fabrication and construction (to minimise material, weld, pipe and coating defects);
- Operations and maintenance (to ensure integrity is maintained);
- Safety management (to ensure all activities are carried out safely).

Quantitative Risk Assessment

Quantified risk assessment (QRA) enables the analysis of the probability and consequences of pipeline failure and the subsequent calculation of risk of death or injury to the population in the vicinity of the pipeline. The calculated risk levels can then be assessed with respect to defined acceptance criteria. The use of QRA for the safety evaluation of pipelines is now accepted practice in the UK[1], and is used at the design stage of major international pipeline projects. The assessment of pipeline safety using QRA rather than simple code compliance assessments draws attention to the need to understand and quantify the differences in pipeline risk levels which may result when different but equally accepted pipeline codes are applied in the design, construction and operation and maintenance of pipelines.

This paper discusses the use of standard pipeline quantitative risk assessment methods to analyse and compare the risk levels of pipelines designed to the codes ASME B31.8[2] and IGE/TD/1[3] (PD 8010 [4]). The QRA utilises predictive models for consequence assessment, e.g. pipeline blowdown and thermal radiation effects, and failure frequency, in determining the risk levels due to an operational pipeline. The results of the analysis illustrate how the risk levels inherent in the two codes compare for different class locations and minimum housing separation distances. The impact of code requirements on design factor, depth of burial, population density and the impact of third party activity on overall risk levels are also discussed.

2. QUANTITATIVE RISK ASSESSMENT METHODOLOGY

The general methodology used in pipeline quantitative risk assessment is well established [5, 6, 7] in the UK and is shown diagrammatically in Figure 1, and briefly described below.

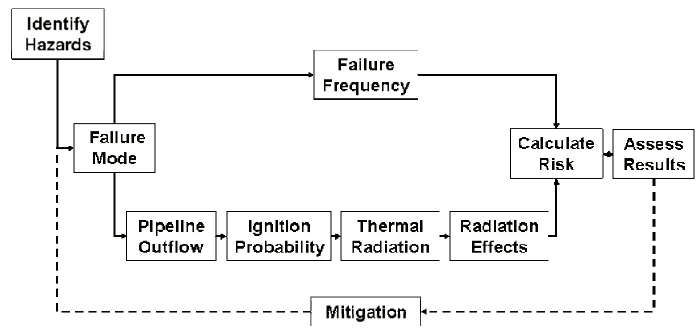

Figure 1: QRA Methodology

Hazard Identification

The first step in any pipeline risk assessment is to identify the credible hazards that may lead to failure, e.g.:

- External damage;
- Corrosion;
- Material & fabrication defects;
- Fatigue;
- Natural events (e.g. ground movement, flooding, lightning strike);
- Operational errors (e.g. overpressurisation, hot tap in error).

External damage due to third parties and natural causes are outside the total control of the operator, so the influence of design is important.

Failure Frequency Evaluation

Pipeline failure frequencies can be taken from historical operational data, although there is limited exposure for modern tough pipeline steels, larger diameters, and higher pressures which makes selecting a valid historical figure difficult.

If the historical failure data is not sufficient, failure frequencies can be predicted using standard pipeline failure equations, distributions of pipeline damage and structural reliability techniques which allow the influence of diameter, wall thickness and grade to be calculated. The United Kingdom Pipeline Operators Association (UKOPA) collect data on pipeline damage incidents and distributions of gouge length and depth and dent depth can be generated from their database[8].

Combining the dent and gouge data with the frequency of pipeline damage (often referred to as the 'hit' rate) allows a prediction of pipeline failure frequency to be calculated. The effect of depth of cover or other mitigation methods, such as concrete slabbing, or factors to account for local incident rates differing from the collected data can also be included to modify the basic prediction.

Pipeline Outflow

If a buried pipeline fails as a rupture, a crater will be formed as soil is thrown clear by the force of the escaping gas. The released gas will initially form a rising mushroom cloud, quickly decaying to a transient jet fed by the outflow of gas from the two pipeline ends. Initially the mass flow rate will rapidly fall until a steady state is reached as shown in Figure 2.[6]

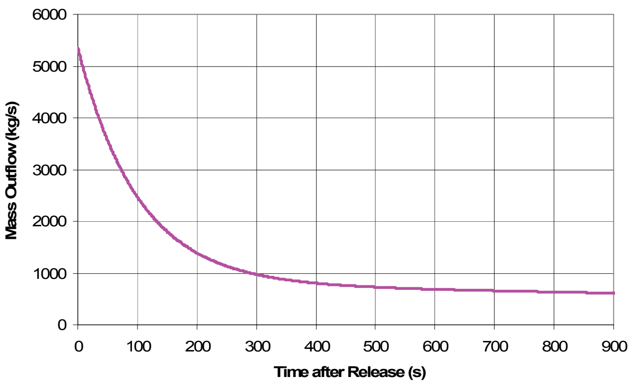

Figure 2: Pipeline Outflow – Full Bore Rupture

Pipeline outflow can be calculated using mathematical models, e.g. standard orifice equations for steady-state leaks, or commercially available software packages, but care must be taken to model the pipeline section boundary conditions adequately, e.g. pressure maintained at the upstream compressor or no reverse flow at downstream sites etc.

Ignition Probability

Following a high pressure natural gas pipeline rupture the emerging plume of lighter-than-air gas is heavily momentum-driven and will tend to rise rapidly into the upper atmosphere before dissipating to concentrations below the lower flammable limit, causing no safety hazard if not ignited.

The probability of ignition can be taken from historical data, see Table 1, or modelled if there are specific local ignition hazards.

It is typical to assume that half of all releases ignite immediately and half are delayed by 30 seconds.

Table 1: Historical Ignition Probabilities[9]

Failure Type	EGIG
Pinhole/crack	3%
Leak	2%
Rupture (≤ 16")	9%
Rupture (> 16")	30%
Overall	4.1%

Thermal Radiation

If ignition occurs immediately, the gas released during the initial mushroom cloud phase will burn as a transient fireball, typically for less than thirty seconds, before burning out to leave a quasi-steady state crater jet fire. If ignition is delayed, then only the quasi-steady state jet fire will occur.

Fireball and jet fire models exist to allow the calculation of incident radiation levels at any distance from the pipeline. [10, 11]. Combining the transient pipeline outflow with the fire models allows the creation of a matrix of thermal radiation values that varies with time from release and with distance from the pipeline.

It is also possible to assume an effective steady state release rate, and produce one set of thermal radiation contours. This method is obviously an approximation of the real transient event; consequently much care must be taken to ensure that the assumed release rate, and associated thermal radiation levels, remain conservative.

Thermal Radiation Effects

People subject to thermal radiation from an ignited pipeline fire are assumed to attempt to escape until they either: reach safe shelter; reach a point where incident radiation has fallen to a low level; or become a fatality. Escape speed should be chosen to reflect the potential difficulties in escaping directly from the fire and/or the terrain to be crossed.

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 incident time, t, and the distance from the pipeline.

Probit dose relationships are used to correlate the thermal dose with fatality probabilities for standard populations. There are some variations in the data [12, 13] but the standard assumption in the UK is to use 1800 thermal dose units (tdu) as a fatality criterion for standard adult populations and 1060 tdu, also known as 1% lethality, for populations sensitive to thermal radiation such as children, the sick and elderly[11].

The minimum distance at which escape without shelter is possible can be calculated by performing the calculation from a range of starting distances from the pipeline.

The time at which buildings ignite when subject to certain levels of heat flux can be calculated from equations for the piloted ignition of wood which were derived from the results of well-known full scale tests [11]. This also allows the calculation of the maximum distance to which buildings will burn due to incident thermal radiation to be calculated. The building burning distance calculated in this way is analogous to the ASME B31.8S HCA distance[14, 15].

Buildings are assumed to provide full shelter from thermal radiation until the time they catch fire. At this point any population sheltering in the ignited building are subject to the relevant incident radiation and must attempt to escape to further shelter or to a safe distance from the fire. As the pipeline will have been blowing down and the quasi-steady state jet fire reducing in size, the incident thermal radiation at this point may have reduced significantly and escape may be possible. This behaviour was exhibited in the Edison, New Jersey incident where there were no casualties due to thermal radiation, despite three apartment blocks burning down[16].

When modelling actual locations, the proportion of time spent outdoors and the varying numbers of people present throughout the day can be incorporated.

Risk Calculation

To calculate the risk to a particular individual or development, it is important to define the length of pipeline that could cause harm. This length is known as the 'interaction length' and for a point on a pipeline is twice the maximum hazard distance. The hazard distances and hence the interaction length vary according to the casualty criterion being used.

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. Planning authorities also often present individual risk using risk contours overlaid on pipeline route maps.

To calculate the individual risk per year along a transect perpendicular to the pipeline, the interaction length is split into steps, and the frequency and consequences of all pipeline incidents, i.e. immediate and delayed ignited ruptures and leaks, calculated for each step and summed for a range of distances along the pipeline.

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 of N or more casualties per year versus N, commonly referred to as an FN curve.

To calculate the societal risk of a specific development, for each step in the interaction length, the failure frequency of the step length, f, and the number of casualties, n, are calculated. These fn pairs are summed for each value of n to produce a histogram which is plotted as a reverse cumulative distribution to produce the FN curve.

In comparison to individual risk, societal risk assessment takes into account the movement of adjacent population throughout the day and can take the layout of developments into account.

Risk Assessment

Once risk levels have been calculated, it is important to determine whether they are acceptable by assessing against risk criteria. Risk criteria may be set by the pipeline company or by local, regional or national government.

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 3[17, 18, 19].

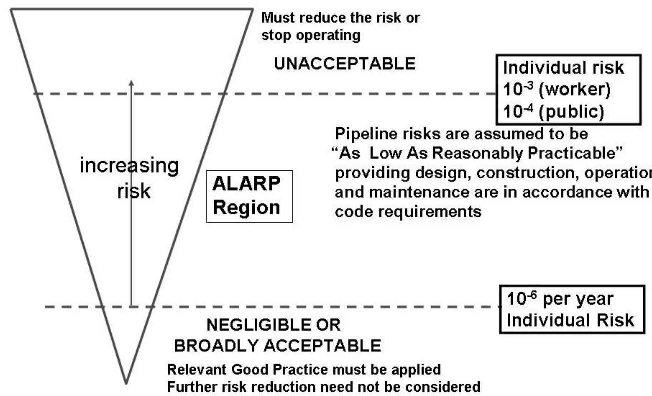

Figure 3: UK HSE Individual Risk Criteria

This diagram defines three regions:

i) The unacceptable region, in which individual risk levels are greater than 1 in 10,000;

ii) The broadly acceptable region, in which risk levels are below 1 in 1,000,000;

iii) A region between these limits in which the risk is tolerable only of further reduction is impractical, or requires actions which are grossly disproportionate to the reduction in risk achieved, i.e. the risk is "as low as reasonably practicable" or ALARP.

For linear hazards like pipelines, where a number of people may be affected by a single incident, it is common use individual risk for screening studies and generic assessments and societal risk to consider the affect on groups of people. Societal risk criteria have been published in Hong Kong, the Netherlands and in IGE/TD/1, see Figure 4.

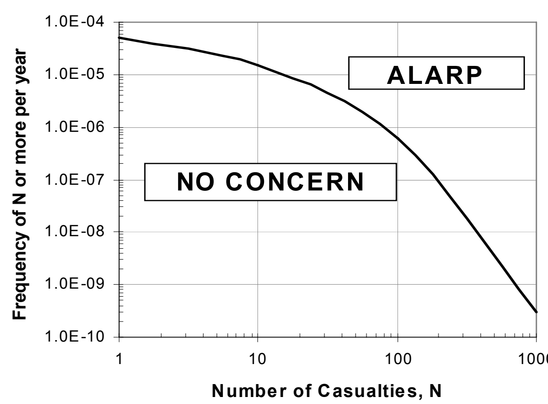

Figure 4: IGE/TD/1 Sample FN Criterion

It is important to remember that FN criteria are related to a specific length of pipeline or case length, 1.6km in the case of IGE/TD/1.

Risk Mitigation

If the calculated risks are found to not be ALARP, then mitigation must be applied to reduce the risk levels to the affected population. This may range from hard engineering actions like relaying the pipeline in thicker wall or installing concrete protection slabs to softer ongoing operational actions such as increased surveillance or the implementation of a one call system[1, 20].

The risk assessment can be re-calculated, with the proposed mitigation measures incorporated and the ensuing risk levels assessed against the ALARP criteria. This is commonly carried out using cost-benefit analysis and the expected casualties per year, calculated from the fn pairs.

3. IMPACT OF PIPELINE CODE REQUIREMENT ON RISK LEVELS

Codes and standards present engineering principles and recognised best practice in a safe, validated manner. Approved industry codes and standards for design, and construction, are developed to ensure the safety of engineering infrastructure. Their use and application is a prerequisite for compliance with safety legislation. In the UK, the Pipelines Safety Regulations set out the duties required to ensure that pipelines are safely managed, and that risks to persons are reduced to a level which is 'As Low as Reasonably Practicable', or ALARP. The guidance to these regulations[21] states that British Standards provide a sound basis for the design of pipelines, but that other national or international standards or codes are acceptable provided that the level of safety achieved is equivalent.

The engineering principles which provide the primary risk controls are applied by the pipeline code during the design of the pipeline. These include the design factor and wall thickness, route definition, material selection, corrosion protection and pipeline protection measures. In the UK, the current pipeline codes PD 8010 and IGE/TD/1 were originally developed from the principles established by the US ASME B31.8 code. These principles and their impact on the risk levels posed by the pipeline are discussed below.

US Code for Gas Pipelines – ASME B31.8

The US codes for pressure piping and pipelines have been developed under Project B31, which was initiated and sponsored by the American Society of Mechanical Engineers in the 1920s. The ASME B31 codes are internationally recognised and applied, and have established the principles and led the international development of codes for the safe design and construction of pipelines. The B31.8 document was published in the 1950s to provide an integrated code for gas transmission and distribution pipelines. This document established the principles for the safe design of gas pipelines, which have subsequently been adopted and adapted in a number of internal and national codes, including the UK.

The design philosophy of ASME B31.8 is based on relating the permissible stress (and therefore pressure) to the number of occupied buildings in the vicinity of the pipeline. The underlying assumption is that the number of underground services and therefore the potential level of activity which may result in damage to a pipeline routed through the area is related to the concentration of buildings intended for human occupancy. The number of occupied buildings in a 1 mile x 0.25 mile wide segment of the pipeline route is used to define the Location Class, and the permissible hoop stress is restricted by reducing the design factor (the ratio of hoop stress to the specified minimum yield strength of the pipeline) as the number of occupied buildings increases.

The ASME B31.8 design process is shown in Figure 5. This shows the definition of Location Classes 1 through to 4, and the maximum design factor specified for each Location Class.

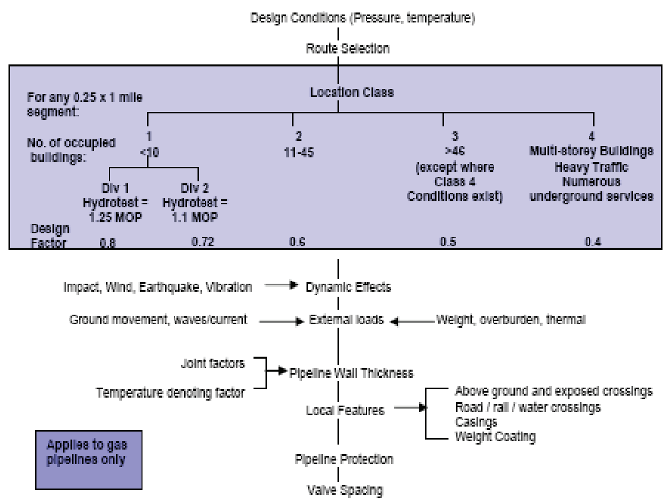

Figure 5: ASME Design Process

While the number of occupied buildings is defined, the level of occupancy is not, so the population density is not explicitly defined.

UK Codes for Gas Pipelines – IGE/TD/1 and PD 8010

The need for a UK specific national pipeline code was recognised in the 1960s, when the development of the gas national transmission system commenced. At that time, pipeline codes applied in the UK[22] were simple interpretations of the American ASME B31 codes. As a result of industry experience, major changes to these codes were being undertaken to address a number of issues, including material properties, fracture propagation and the need for pre-commissioning testing.

In adopting and developing the philosophy of the ASME B31 codes for wide implementation in the UK, it was necessary to accommodate a higher level of land development and higher population densities.

The current edition of IGE/TD/1, Edition 4[3], was published in 2001. In 1989, The British Standards Institution published the pipeline code BS 8010, and in 1992 Section 2.8 of this standard, covering steel pipelines for oil and gas was published[23]. BS 8010 was revised and updated, and published as the Published Document (PD) 8010 in 2004[4]. PD 8010 states that the design guidance for natural gas pipelines is based on IGE/TD/1, and refers directly to these recommendations.

The IGE/TD/1 (and therefore the PD 8010) code extends the ASME B31.8 approach for controlling the probability and limiting the consequences of pipeline failure by defining an area type based on an explicit definition of population density, and specifying a minimum distance from the pipeline to normally occupied buildings based on the maximum operating pressure (MOP) (i.e. the building proximity distance) as well as the maximum design factor for the area type.

Specifically the IGE/TD/1 design approach involves:

- Categorisation of the area type through which the pipeline operates according to population density as Rural (R, ≤ 2.5 persons per hectare),
  Suburban (S, > 2.5 persons per hectare) and
  Town (T, significant development)
- Defining a minimum allowed distance between the pipeline and the nearest occupied building (the building proximity distance, BPD) according to pipeline diameter, pressure and minimum wall thickness.
- Specifying the area over which the population density is assessed as a strip 1.6 km long x 8 BPD wide centred on the pipeline.
- Allowing a design factor of 0.72 in R areas, but limiting it to 0.3, or 0.5 if wall thickness is ≥ 19.05 mm, in S areas to minimise the likelihood of rupture, and preventing the routing of high pressure pipelines through T areas.

A simple outline of the design philosophy is given in Figure 6.

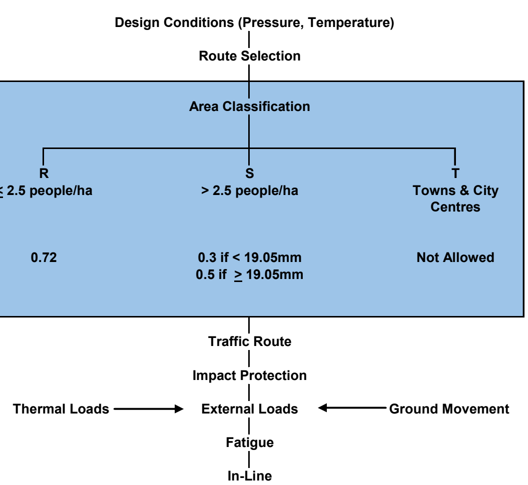

Figure 6: IGE/TD/1 Design Process

Risk Levels

The above overview of the US and UK pipeline codes shows that the basic design philosophy in ASME B31.8 code recognises that the most significant factor contributing to the possible failure of a gas pipeline is external interference caused by activities along the route. The level of activity is directly related to the level of building development and hence population density. To take account of this, the maximum stress (and therefore minimum wall thickness) is related to density of occupied buildings in vicinity of the pipeline. This design philosophy is further extended in IGE/TD/1 to minimise the likelihood and consequences of failure in the higher levels of development and population density in the UK, through the specification of a minimum distance between the pipeline and normally occupied buildings, which is based on the diameter, wall thickness, and pressure of the pipeline.

Based on the above, the key parameters in the design philosophy for gas pipelines are:

i) Maximum stress in Location Class/Area Type;
ii) Minimum wall thickness;
iii) Population density;
iv) Proximity of the population to the pipeline.

In addition, a further parameter which has an accepted influence on the likelihood of damage due to external interference is the depth of burial. ASME B31.8 and IGE/TD/1 specify different values for this parameter, so it must be taken into account in any consideration of risk levels.

The potential hazard of gas pipelines, and the impact of the ASME B31.8 and IGE/TD/1 requirements on the inherent risk level of the pipelines can be directly quantified and compared using quantified risk analysis (QRA). To do this requires that the codes are applied to the design of equivalent pipelines, and the inputs to the QRA derived. The derivation and comparison of each of the above parameters using i) ASME B31.8 and ii) IGE/TD/1 is therefore considered in more detail below.

Maximum Stress

Both ASME B31.8 and IGE/TD/1 (PD 8010) define the maximum stress in terms of a maximum design factor for a specific location. A comparison of the definitions of ASME B31.8 Location Class and IGE/TD/1 Area Types is shown in Table 2 below.

This comparison indicates that ASME Location Classes 1 and 2 both cover the definition of the IGE/TD/1 Area Type R, and ASME Locations Classes 2 and 3 both cover the definition of the Area Type S. Note that while the qualitative descriptions of the ASME Location Classes are more detailed than the definitions of the IGE/TD/1 Area Types, the Area Type definition is primarily based on population density although the boundary between Types S and T is subjective.

A comparison of risk levels is therefore required to compare risks in Locations Classes 1 and 2 with the risk in Area Type R, and risks in Location Classes 2 and 3 with the risk in Area Type S. The IGE/TD/1 design factor in Area Type S is lower, and is equivalent to the ASME Location Class 3 value only for thick wall pipe.

Table 2: ASME B31.8 and IGE/TD/1 Design Factor and Location Class Comparison

<table>
<tr><th colspan="2">ASME B31.8</th><th colspan="2">IGE/TD/1</th></tr>
<tr><th>Location Class</th><th>Design Factor</th><th>Area Type</th><th>Design Factor</th></tr>
<tr><td>1
Wasteland, deserts, mountains, grazing and farmland, sparsely populated areas</td><td>0.72</td><td rowspan="2">R
Rural areas, agricultural land</td><td rowspan="2">0.72</td></tr>
<tr><td rowspan="2">2
Areas where population is intermediate between 1 and 3, i.e. fringe areas around towns and cities, industrial areas, ranch/country estates</td><td rowspan="2">0.6</td></tr>
<tr><td rowspan="2">S
Areas intermediate between R and T, which may be extensively developed with residential developments, schools, shops etc</td><td rowspan="2">0.3
(0.5 if t ≥ 19.05mm)</td></tr>
<tr><td>3
suburban housing developments, shopping centers, residential and industrial areas</td><td>0.5</td></tr>
<tr><td>4
Multi-storey buildings, dense traffic, numerous underground utilities</td><td>0.4</td><td>T
Central areas of towns and cities, multi-storey buildings, dense traffic, numerous underground services</td><td>Not applicable</td></tr>
</table>

Wall Thickness

Pipeline wall thickness is determined for both codes using the Barlow equation to specify the hoop stress level in terms of the specified minimum yield stress (SMYS) of the pipe material.

However, the codes differ in that ASME B31.8 specifies wall thickness, t, to be the nominal value, whereas IGE/TD/1 specifies t to be the minimum (i.e. nominal minus manufacturing tolerance) pipe wall thickness. This means that the IGE/TD/1 design factors are effectively lower than their ASME B31.8 equivalents. Or alternatively, that pipelines designed to ASME B31.8 will have a thinner wall than those designed to IGE/TD/1 for the same design factor.

Population Density

ASME B31.8 specifies the maximum number of occupied buildings in each Location Class, but does not define a population density. However, a population level is defined as 20 or more people for areas of public assembly or concentrations of people in Location Classes 1 and 2.

IGE/TD/1 specifies a population density limit of 2.5 persons per hectare in Area Type R, and a population density of greater than 2.5 persons per hectare (2.471 acres) for Area Type S. However, a maximum population density for S areas is not specified.

IGE/TD/1 recommends that population density should be estimated based on a survey, e.g. aerial photography, of normally occupied buildings and premises where people congregate for significant periods of time. The occupancy of houses can either be determined from Census figures or assumed as 3 per dwelling.

Table 3: Comparison of Population Density Requirements

<table>
<tr><th colspan="2">ASME B31.8</th><th colspan="2">IGE/TD/1 (PD 8010)</th></tr>
<tr><th>Location Class</th><th>Number of Buildings</th><th>Area Type</th><th>Max. Population Density (/ha)</th></tr>
<tr><td>1</td><td>0 - 10</td><td rowspan="2">R</td><td rowspan="2">2.5
(1.01/acre)</td></tr>
<tr><td rowspan="2">2</td><td rowspan="2">11 - 45</td></tr>
<tr><td rowspan="2">S</td><td rowspan="2">Not specified</td></tr>
<tr><td>3</td><td>> 46</td></tr>
<tr><td>4</td><td>Not specified</td><td>T</td><td>Not applicable</td></tr>
</table>

Proximity of the Population to the Pipeline

ASME B31.8 does not specify a minimum proximity distance between the pipeline and occupied buildings, but it has been assumed that there will be a minimum 3m (9.8ft) easement either side of the pipeline to allow for future maintenance access.

IGE/TD/1 specifies a minimum building proximity distance (BPD) between the pipeline and occupied buildings, defined according to the pipeline pressure, diameter and wall thickness. The minimum is 3m (9.8ft) for S area pipelines with a wall thickness greater than 11.91mm (0.469").

Proximity of occupied buildings to the pipeline affects both the failure frequency due to external interference and the number of casualties given an ignited pipeline incident.

4. RISK ANALYSIS OF PIPELINE DESIGNS

Compliance with the risk based UK Pipeline Safety Regulations requires that the risk level of the pipeline design is considered and evaluated, and that where codes other than PD

8010 or IGE/TD/1 are used, the risk levels should be shown to be equivalent. In the UK, ASME B31.8 is a recognised alternative to PD 8010 and IGE/TD/1, although the risk levels inherent in ASME B31.8 designs are generally considered to be higher than the inherent risk levels in the UK codes. In order to obtain an understanding of the inherent risk levels, a case study to compare the risk levels has been carried out.

Case Study Description

A typical transmission pipeline of 36” (914.4mm) diameter, 75 bar maximum allowable operating pressure and X65 grade was chosen as the basis for the case study. Wall thicknesses have been selected to exactly meet B31.8 and IGE/TD/1 design factor requirements for each location class and not rounded up to the next standard size. The relevant code minimum depth of cover was taken to apply. The basic pipeline design parameters for each case are shown in Table 5 below.

As discussed in Section 3 the location classes or area type in each code specify a design factor limit and an associated maximum population or population density within a specified area. Where each code specifies an upper bound for the number of houses or population density, this maximum has been used in the case study. For ASME B31.8 Class 3 and IGE/TD/1 Type S where the upper bound is not well defined, a population density of 10 persons per hectare has been taken. To convert between number of houses and population density, it has been assumed that there are three occupants per dwelling.

Each case study has been modelled as an area 1.6 km long by 800 m wide (0.99 by 0.5 miles) with the pipeline running in a straight line through the centre. Housing has been assumed to be evenly spread through the case study area, outside of any minimum separation distance, as illustrated in Figure 7 below.

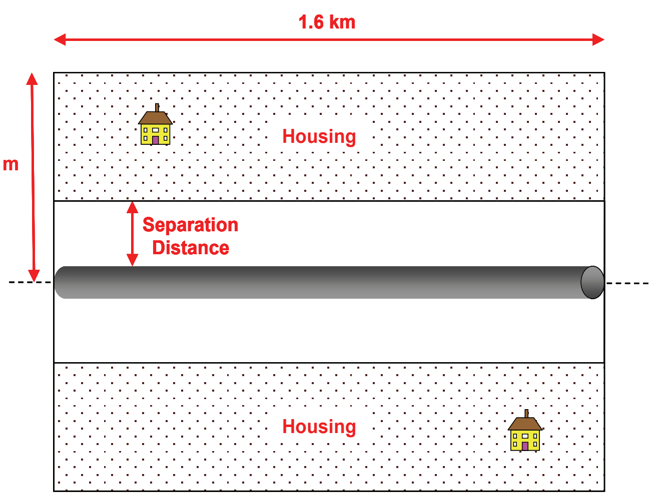

Figure 7: Case Study Area

Case Study Assessment

The QRA of the 6 case studies was completed following the methodology described previously. As the cases are generic with uniform population shelter density, individual risk only has been calculated.

Blowdown and thermal radiation calculations were performed using Shell FRED (Fire, Release, Explosion and Dispersion)[24]. For this case study, no account was taken of variations in wind direction or stability.

Failure frequency predictions were calculated in a Penspen in-house software program PI-FAIL using Monte-Carlo simulation techniques, standard pipeline failure equations[25,26] and probabilistic UKOPA pipeline damage data[8]. All other pipeline parameters are treated deterministically.

The UKOPA damage database provides hit rate data for pipelines in the UK designed to IGE/TD/1 and PD 8010, i.e. split by R and S areas, and consideration is needed to apply the same predictions to ASME B31.8 due to the differences in population proximity and density.

Table 4 summarises the assumed factors used in this case study. Location class 3 has been assumed to be equivalent to an S area and Location Class 1 has been assumed to have half the hit rate of an R area due to the reduced population. Location Class 2 has been assumed to be midway between Area Types R & S.

Table 4: Assumed Hit Rate Factors

ASME B31.8		IGE/TD/1 (PD 8010)	
Location Class	Hit Rate Factor	Area Type	Hit Rate Factor
1	0.5	R	1
2	2.45		
3	3.9	S	3.9

Thermal radiation effects to people and property from leaks and ruptures and individual risk calculations were carried out using a Penspen in-house software program, PI-RISK, Ignition probabilities for both leaks and ruptures were taken from Table 1 and the 1800 tdu casualty criterion was used for this case study.

Hazard and Frequency Analysis Results

The predicted pipeline failure frequencies due to external interference are shown in Table 6. It can be seen that Case 2 has the highest predicted failure frequency due to a combination of high hit rate factor and relatively thin wall thickness.

The calculated hazard distances for both immediate and delayed ignition of ruptures are shown in Table 7.

The calculated building burning distance is shown to have good agreement to the equivalent HCA distance.

Table 5: Summary of Case Study Design Parameters

Case	1	2	3	4	5	6
Design Code	ASME B31.8	ASME B31.8	ASME B31.8	IGE/TD/1	IGE/TD/1	IGE/TD/1
Outside Diameter (mm)	914.4 (36”)					
MAOP (bar)	75 (1088 psi)					
Grade	X65					
Location Class	1 (Div 2)	2	3	R	S	S
Design Factor	0.72	0.6	0.5	0.72	0.42	0.3
Nominal Wall Thickness (mm)	10.63 (0.419”)	12.76 (0.502”)	15.31 (0.603”)	11.19 (0.441”)	19.05 (0.75”)	26.86 (1.057”)
Depth of Cover (m)	0.610 (24”)	0.762 (30”)	0.762 (30”)	1.1 (43.3”)	1.1 (43.3”)	1.1 (43.3”)
Min. Distance to Housing (m)	3 (9.84 ft)	3 (9.84 ft)	3 (9.84 ft)	81 (265.75 ft)	3 (9.84 ft)	3 (9.84 ft)
Population Density (/ha)	0.463 (0.187/acre)	2.131 (0.862/acre)	10 (4.047/acre)	2.5 (1.012/acre)	10 (4.047/acre)	10 (4.047/acre)

Table 6: Predicted Failure Frequencies due to External Interference

Case	1	2	3	4	5	6
Wall Thickness (mm)	10.63 (0.42”)	12.76 (0.50”)	15.31 (0.60”)	11.19 (0.441”)	19.05 (0.75”)	26.86 (1.06”)
Leak Frequency (x 10^{-6} km years)	18.126	46.783	35.555	27.305	12.255	1.190
Rupture Frequency (x 10^{-6} km years)	24.192	34.823	14.138	30.143	2.499	0.119

Table 7: Predicted Hazard Distances

	Immediate Ignition	Delayed Ignition
Building Burning Distance (m)	256 (280.0 yd)	241 (263.6 yd)
HCA Distance (m)	248 (271.2 yd)	
Escape Distance (without shelter) - Standard Population (m)	520 (568.7 yd)	500 (546.8 yd)
Escape Distance (without shelter) - Vulnerable Population (m)	740 (809.2 yd)	730 (798.3 yd)

5. COMPARISON OF INHERENT RISK LEVELS

Individual risk is the frequency at which an individual at a specified distance from the pipeline is calculated to be a casualty at a specified level of harm from the realisation of specific hazards.

Individual risk transects obtained for the pipeline case studies are shown in Figures 8, 9 & 10 below. All figures show that within 200m (218.7yd) from the pipeline, or approximately 2.5 times the IGE/TD/1 BPD, the individual risk level remains relatively constant. This is due to the high probability that buildings will ignite and burn eliminating the possibility of people finding shelter.

Beyond this distance, the individual risk decreases as a result of the increasing likelihood of people finding shelter. Between 200 – 350m, (or 3-4 BPDs), generally only people outdoors are potential casualties.

ASME B31.8 Risk Levels

Considering first the risk levels inherent in the ASME B31.8 pipeline designs, the differences in the risk analysis input parameters for the three cases are the wall thickness, hit rate factor and shelter density.

Figure 8 shows that the Location Class 2 design risk level at the pipeline approximately 1.4 times higher than the Location Class 1 design risk level. The differences in the risk level at this point are influenced primarily by the wall thickness (and therefore the failure rate) and the hit rate factor.

Beyond a distance of 200m (218.7yd) from the pipeline, the Location Class 2 risk level falls below the Location Class 1 risk level, as the increased shelter density (which is due to the higher population density) increases the likelihood of escape.

The Location Class 2 design level is approximately 2.6 times greater than the Location Class 3 design risk level at the pipeline. In this case, the increased wall thickness of the Location Class 3 design offsets the increased area factor for this location class. Again the increased shelter density in Location Class 3 results in a more rapid reduction in the risk level at distances beyond 200m (218.7yd) from the pipeline.

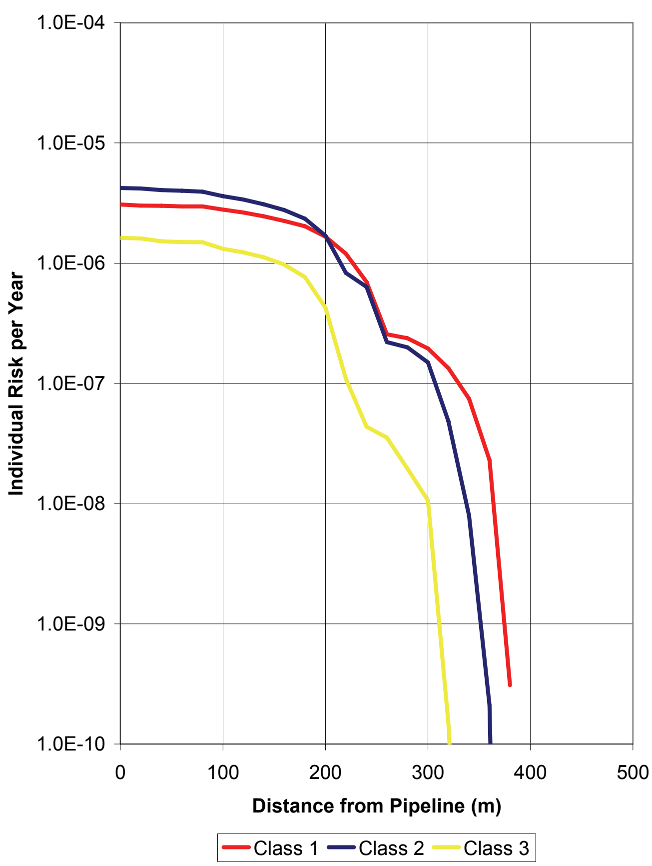

Figure 8: Individual Risk Transects for ASME B31.8 Cases

IGE/TD/1 Risk Levels

When considering the IGE/TD/1 design risk levels, in addition to the pipeline wall thickness, area factor and shelter density, the distance of the population from the pipeline also varies. As shown in Figure 9 the risk level in the IGE/TD/1 R area design at the pipeline is approximately 260 times higher than the risk level for the Type S area 26.86mm design, or 0.3 design factor, of Case 5.

This difference occurs despite the much greater separation between the pipeline and population in the R area design, and demonstrates the significant reduction in risk which results from the much lower design factor and increased wall thickness.

IGE/TD/1 allows a higher design factor (up to 0.5) in Area Type S if the pipe wall thickness is equal to or greater than 19.05mm (0.75”). For the case study being considered, a wall thickness of 19.05mm results in a design factor of 0.42. The results in Figure 9 show that while the risk level for this design is 21 times higher than the risk level at a design factor of 0.3, it is still approximately 12 times lower than the Area Type R design.

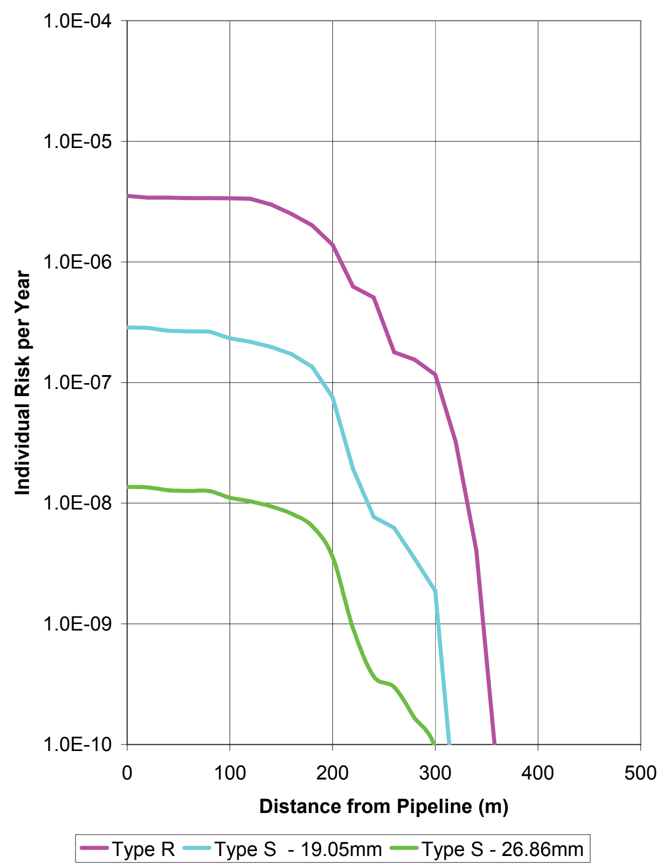

Figure 9: Individual Risk Transects for IGE/TD/1 Cases

Comparison of Risk Levels

When comparing the risk levels inherent in the ASME B31.8 designs with those inherent in the IGE/TD/1 designs, the results are influenced by changes in the pipeline wall thickness, depth of cover, area factor, shelter density and the distance of the population from the pipeline.

The results in Figure 10 show that the risk level in the IGE/TD/1 Area Type R design is very similar to, and falls between, the risk levels for the ASME B31.8 Location Class 1 and 2 designs. Beyond the 200m distance from the pipeline, the IGE/TD/1 Area Type R risk level is very similar to the ASME

Location Class 2 design risk level, despite the slightly lower wall thickness. This is due to the increased separation between the pipeline and population, and the increased shelter density due to the slightly higher population density in the IGE/TD/1 Area Type R design.

The risk level at the pipeline in the ASME B31.8 Location Class 3 design is approximately 119 times higher than the risk level in the IGE/TD/1 Area Type S design of Case 6. In this case, the area factor and shelter density are equivalent, but the ASME Location Class 3 design factor is much higher than the IGE/TD/1 Area Type S design factor. The risk level for the ASME Location Class 3 design is also approximately 5.7 times higher than the 19.05mm wall thickness Case 5.

The comparison of results demonstrates the impact of design parameters on the predicted risk levels and clearly indicates the difference in the inherent risk levels in the ASME B31.8 and IGE/TD/1. However, in all the case studies considered, more than one input parameter varies, so it has not been possible to evaluate the change in risk level resulting from a specific change in an input parameter. In addition, some of the risk analysis inputs, such as the area factor, are not specified by the codes, while other input parameters, such as the shelter density, are case-specific.

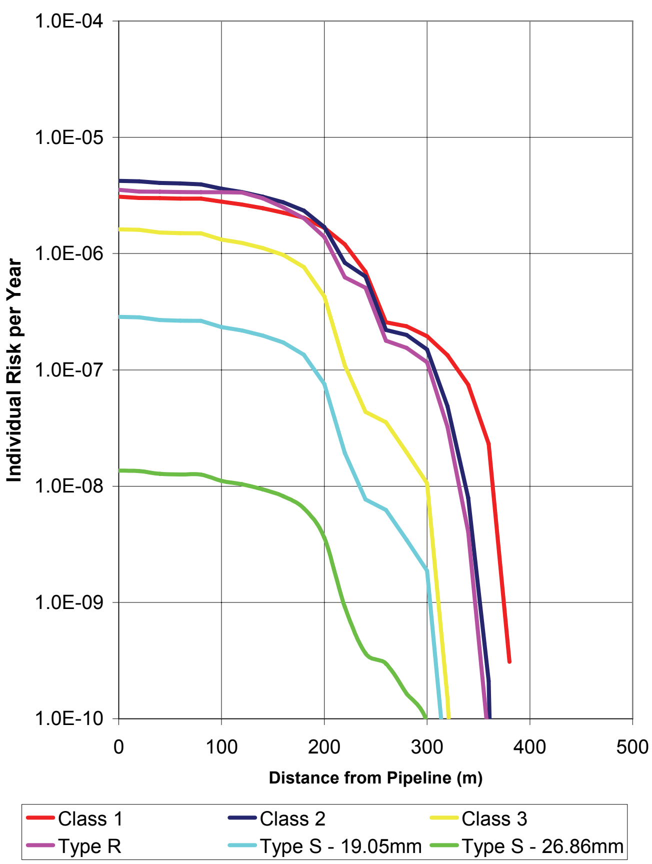

Figure 10: Individual Risk Transects for all Cases

6. CONCLUSIONS

The inherent individual risk levels in pipeline codes in the US and UK have been compared. Six case studies have shown, that using the assumptions in the case study:

1. The risk levels in ASME B31.8 Location Class 1 and 2 designs and IGE/TD/1 Area Type R are similar;
2. The risk level in ASME B31.8 Location Class 3 is considerably higher than in IGE/TD/1 Area Type S.

These conclusions confirm that the design approach implemented in IGE/TD/1 in the UK, to address the higher levels of land development and population density, was successful in reducing inherent risk levels as originally envisaged.

The methodology presented here could also be used to adapt the ASME B31.8 location classes for application in other countries, with differing typical building densities, proximity distances, activity rates etc. These variables can be defined to ensure that the risk levels inherent in ASME B31.8 is maintained in differing environments and countries if required.

Further Work

The results of the case study are dependent on the assumptions used for typical population density in Class 3 and Type S areas, hit rate factors for ASME B31.8 Class locations etc. and the values used should be confirmed.

Sensitivity studies would also enable the change in risk level with a specific change in input parameter to be quantified, and detailed consideration of a real pipeline design case study would allow more realistic consideration of risk analysis input parameters which are not specified by the codes and full societal risk assessment be carried out.

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REFERENCES

1 Corder, I, 1995 “The Application of Risk Techniques to the Design and Operation of Pipelines”, C502/016, pp.113-125, IMechE.

2 Gas Transmission and Distribution Piping Systems, ASME B31.8-2003, American Society of Mechanical Engineers, 2003.

3 Steel Pipelines for High Pressure Gas Transmission, Recommendations on Transmission and Distribution

Practice, IGE/TD/1 Edition 4, 2001, Institution of Gas Engineers, UK.
4 Code of Practice for Pipelines – Part 1: Steel Pipelines on Land, PD 8010, British Standards Institution, 2004.
5 Goodfellow, G.D., 2005, "The Use of Pipeline Risk Assessment in the EU", presentation to the GCC-EU Seminar on Natural Gas Advanced Technologies - Realities and Prospects, Doha, Qatar, February 7-8, 2005, http://eugccseminar.epu.ntua.gr.
6 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.
7 Bilo M. & Kinsmann, P., 1997, "MISHAP – HSE's pipeline risk-assessment methodology", Pipes & Pipelines International, **42**(4), July-August, pp.5-12.
8 Francis A., 2000, "The Use of Damage Data for Predictive Modelling", presented at the UKOPA Conference, Runcorn, UK, 30th November 2000.
9 "Gas Pipeline Incidents 1970 – 2004", 6th Report of the European Gas Pipeline Incident Group, EGIG 05.R.0002, December 2005.
10 Mannan, S. eds., 2005, *Lees' Loss Prevention in the Process Industries,* 3rd Edition, Elsevier Butterworth-Heinemann, Oxford, UK.
11 Bilo, M & Kinsmann, P.R., 1997, "Thermal Radiation Criteria Used in Pipeline Risk Assessment", Pipes & Pipelines International, **42**(5), November-December, pp.17-25.
12 Eisenberg, N.A. et al, 1975, "Vulnerability model: a simulation model for assessing damage resulting from marine spills", (VM1), ADA-015-245 US Coast Guard.
13 Tsao, C.K. & Perry, W.W., 1979, "Modifications to the Vulnerability Model: a simulation system for assessing damage resulting from marine spills" (VM4), ADA-075-231, US Coast Guard.
14 Managing System Integrity of Gas Pipelines, ASME B31.8S-2004, American Society of Mechanical Engineers, 2005.
15 Stephens, M.J., Leewis, K. & Moore, D.K., 2002, "A Model for Sizing High Consequence Areas Associated with Natural Gas Pipelines", IPC2002-27073, Proceedings of IPC'02, 4th International Pipeline Conference, American Society of Mechanical Engineers, September 29 – October 3, Calgary, Alberta, Canada.
16 "Pipeline Accident Report, Texas Eastern Transmission Corporation Natural Gas Pipeline Explosion and Fire, Edison New Jersey, March 23 1994", National Transportation Safety Board, NTSB/PAR-95/01.
17 Anon, 1992, *The Tolerability of Risk from Nuclear Power Stations*, HMSO, London 1992.
18 Anon, 1993, *Guidelines on Risk Issues*, The Engineering Council, London, 1993.
19 Anon, *Reducing risks, protecting people. HSE's decision-making process*, HMSO, London 2001.
20 Anon, 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.
21 Anon, *The Pipeline Safety Regulations 1996 - Guidance on Regulations*, HMSO, 1996.
22 Code of Practice for Pipelines, Part 2 – Design and Construction of Steel Pipelines on Land, CP 2010-2 1970, British Standards Institute, London, 1970.
23 Code of Practice for Pipelines, Part 2 – Pipelines on Land: Design Construction and Installation, Section 2.8 – Steel for Oil and Gas, BS 8010, British Standards Institute, London, 1992.
24 Shell FRED v4.0, Shell Global Solutions, UK, 2005.
25 Cosham, A. & Hopkins, P., 2002, "The Pipeline Defect Assessment Manual", IPC02-27067, Proceedings of IPC'02, 4th International Pipeline Conference, American Society of Mechanical Engineers, September 29 – October 3, Calgary, Alberta, Canada.
26 Cosham, A. & Hopkins, P., "The Effect of Dents in Pipelines – Guidance in the Pipeline Defect Assessment Manual", International Journal of Pressure Vessels and Piping, **81**, 2004, pp. 127-139.