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PIPELINE RISK ASSESSMENT: NEW GUIDELINES

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ABSTRACT

Risk management is a system for dealing with the likelihood that a future event will cause some kind of harm to, e.g., people, the environment, your business, etc.. Risk management provides strategies, processes, resources and tools to monitor, recognise, and deal with a risk event. Pipeline standards and regulations are increasingly requiring pipeline operators to use risk management to ensure pipeline safety.

A major element of risk management is a risk assessment where we quantify the probability of a failure and a consequence of a failure. Most companies and countries use 'qualitative' risk assessments where risk is characterised (or ranked) but not quantified. Some of the limitations of this type of risk analysis can be overcome by using 'quantitative' risk assessments, which use numerical estimates of probability and consequence to calculate risk.

There is recognised guidance available for conducting qualitative risk assessments of pipelines; for example, ASME B31.8S and API 1160, but there is limited guidance on conducting quantitative risk assessments.

In 2009, two documents were produced in the UK that present guidance on quantitative risk assessments:

- Institution of Gas Engineers and Managers: 'Application of pipeline risk assessment to proposed developments in the vicinity of high pressure Natural Gas pipelines', IGEM/TD/2.
- British Standards Institution: Code of Practice – Part 3: Steel pipelines on land – Guide to the application of pipeline risk assessment to proposed developments in the vicinity of major accident hazard pipelines containing flammables – Supplement to PD 8010:2004', PD 8010-3:2009.

These similar documents are based on established 'best practice' principles and methodologies in quantitative risk assessments and were developed by 'UKOPA' - The United Kingdom Onshore Pipeline Operators Association. UKOPA represents the views and interests of UK pipeline operators responsible for major accident hazard pipelines (MAHPs) regarding safety, legislative compliance and best practice.

This paper presents an overview of the new documents in relation to consequence modelling, prediction of failure frequency, application of risk criteria, and implementation of risk mitigation.

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1. INTRODUCTION

Pipelines are a very safe method for transporting hydrocarbons, but like any engineering structure they can fail, and these failures may have serious consequences on the surrounding population and environment. Consequently, it is essential that we manage pipeline risk, and both prevent failures, and mitigate the consequences of any failure.

1.1 Risk Management

Risk management is a system for dealing with the likelihood that a future event will cause some kind of harm to people, the environment, your business, etc.. Risk management provides strategies, processes, resources and tools to monitor, recognise, and deal with a risk event. Pipeline standards and regulations are increasingly requiring pipeline operators to use risk management.

A major element of risk management is a risk assessment where we quantify the probability of a failure and a consequence of a failure, and then compare the calculated risk to an 'acceptable' or 'target' risk level, **Figure 1**. Most companies and countries use 'qualitative' risk assessments where risk is characterised (or ranked) but not quantified. Some of the limitations of this type of risk analysis can be overcome by using 'quantitative' risk assessments, which use numerical estimates of probability and consequence to calculate risk.

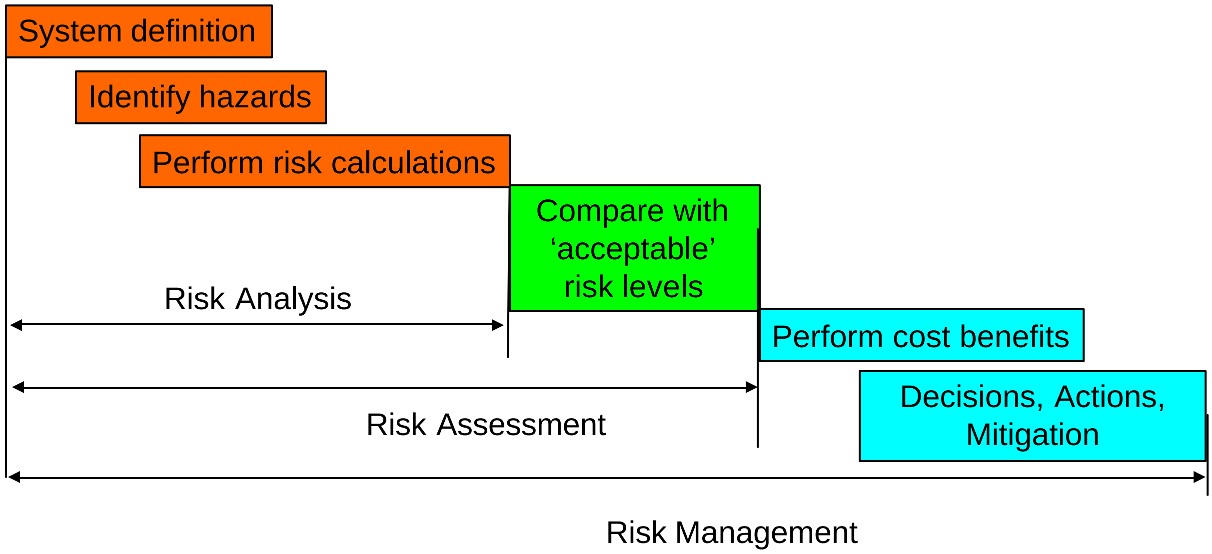

Figure 1. Risk Analysis, Assessment and Management [1].

There is recognised guidance available for conducting qualitative risk assessments; for example, API 1160 [2] and ASME B31.8S [3] but there is limited guidance on conducting quantitative risk assessments.

1.2 New Guidance

In 2009, two documents were produced in the UK that present guidance on quantitative risk assessments:

- *Institution of Gas Engineers and Managers*: 'Application of pipeline risk assessment to proposed developments in the vicinity of high pressure Natural Gas pipelines', IGEM/TD/2 [4].

- *British Standards Institution*: Code of Practice – Part 3: Steel pipelines on land – Guide to the application of pipeline risk assessment to proposed developments in the vicinity of major accident hazard pipelines containing flammables – Supplement to PD 8010:2004', PD 8010-3:2009 [5].

These documents are based on established 'best practice' principles and methodologies in quantitative risk assessments and were developed by 'UKOPA' - The United Kingdom Onshore Pipeline Operators Association. UKOPA represents the views and interests of UK pipeline operators responsible for major accident hazard pipelines (MAHPs) regarding safety, legislative compliance and best practice.

1.3 Use in Land Use Planning

Risk assessments have many uses, including:

- they can be used at the design stage of a pipeline; for example, to justify higher operating stresses than permitted in standards;
- they can be used during operation to assess the risk posed by the pipeline to new building developments around the pipeline.

The latter use is important in heavily-populated countries. In the UK, the plans for any new development around a hazardous pipeline have to be sent by Local Planning Authorities to the Health & Safety Executives (HSE) for their advice. If application of this process indicates that the risks posed by the 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 HSE use quantified risk analysis to calculate risk-based distances around the development based on various individual risk[3] criteria. It is essentially a screening process using 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.

This paper presents an overview of the new documents in relation to consequence modelling, prediction of failure frequency, application of risk criteria, and implementation of risk mitigation. The paper is a continuation of other publications by UKOPA [6, 7, 8].

[3] See Section 4.8 later.

2. RISK ASSESSMENT

Risk is the probability of an event occurring, and the consequences of this event. For example, the 'risk' of us having an automobile accident (the hazard, or the event), is the probability of us being involved in an accident, and the consequences of being in that accident.

Hazard means anything that can cause harm (e.g. chemicals, electricity, working from ladders, etc.), whereas risk is the chance, high or low, that somebody will be harmed by the hazard.

There are differences between risk analyses, assessments and management (**Figure 1**):

- Risk analysis - the estimation of risk from the basic activity.
- Risk assessment - a review as to acceptability of risk based on comparison with risk standards or criteria, and the trial of various risk reduction measures.
- Risk management - the process of selecting appropriate risk reduction measures and implementing them in the on-going management of the activity.

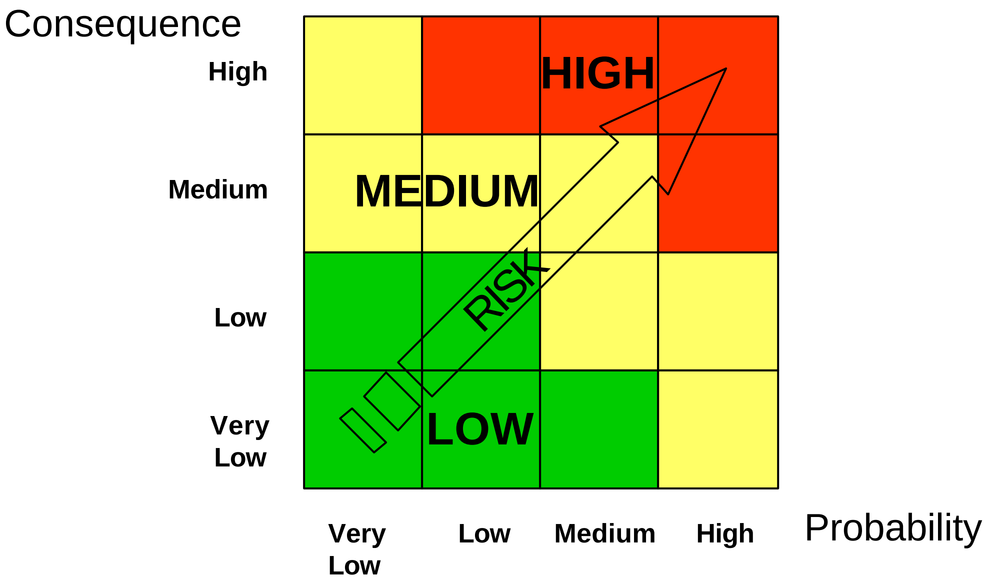

Figure 2. Qualitative Risk Analysis [10].

We can have two approaches to risk analysis [9]:

a *Qualitative*: we characterise (or rank) risk, but do not quantify it (**Figure 2**); for example:

- An old gas pipeline in a heavily populated area could be estimated to have a risk of causing a fatality of '8' (on scale of 1 to 10, where 10 is high);
- New crude oil line in a desert. Risk is 2;
- New gas line in a rural area. Risk is 3.

b *Quantitative*: we calculate risk based on numerical estimates of probability and consequence (**Figure 3**):

- Probability of a plane crash = 1 x 10^{-6};
- Consequences of a crash is 100 fatalities;
- Risk = 1 x 10^{-4} fatalities/flight.

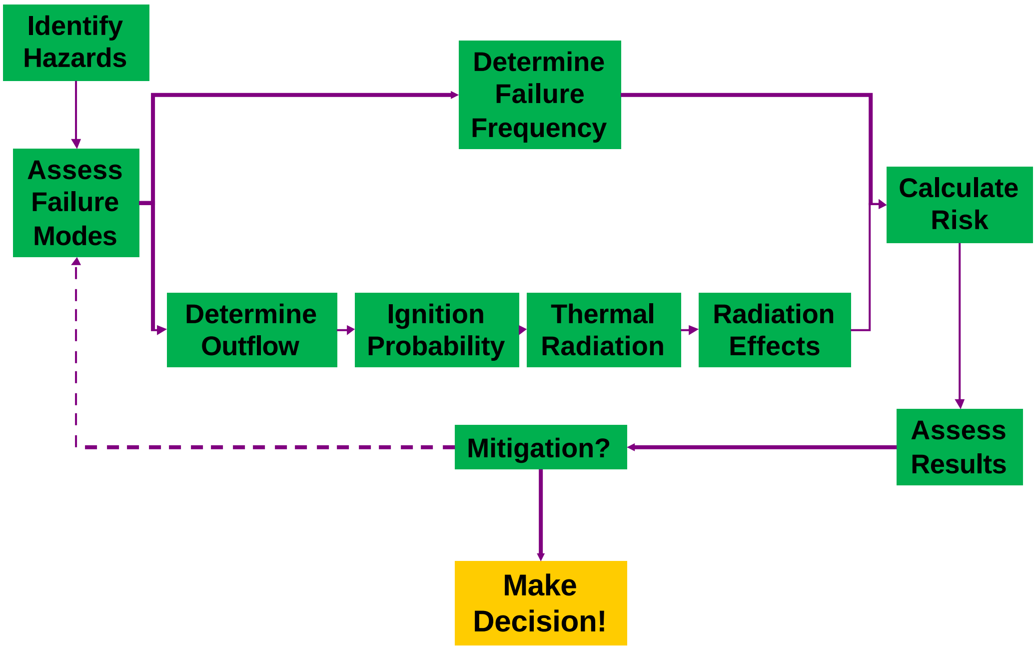

Figure 3. Quantitative Risk Analysis [10].

Qualitative risk analysis is the most popular approach in the pipeline industry, as quantitative risk analysis requires detailed and extensive pipeline data such as failure frequencies. **Figure 3** illustrates some of the requirements of a quantitative risk assessment which include a quantitative determination of failure frequency, failures modes, radiations effects, etc..

4.4 Qualitative Risk Analysis

In the USA 'integrity management' regulations imposed on both liquid and gas pipelines have lead to the development of industry consensus standards on managing pipeline integrity, which include qualitative risk analysis guidance.

The American Petroleum Institute (API) has developed a standard [2] that gives guidance on developing integrity management programmes to satisfy the new regulations. A risk assessment is a key part of API 1160. ASME B31.8S [3] is a similar guidance document for gas lines.

The goal of an API 1160 risk assessment is to identify and prioritise all pipeline threats, which means a qualitative risk assessment is acceptable. The steps are:

- Form expert team;
- Agree structured approach;
- Identify risks, using both past/present data, but focus on future possible mishaps;
- Quantify and rank risks;

- Mitigate high risks;
- Ensure a feedback loop, as new data is continuously generated;
- Review and audit.

Figure 4 shows how risk assessments are also central to ASME B31.8S.

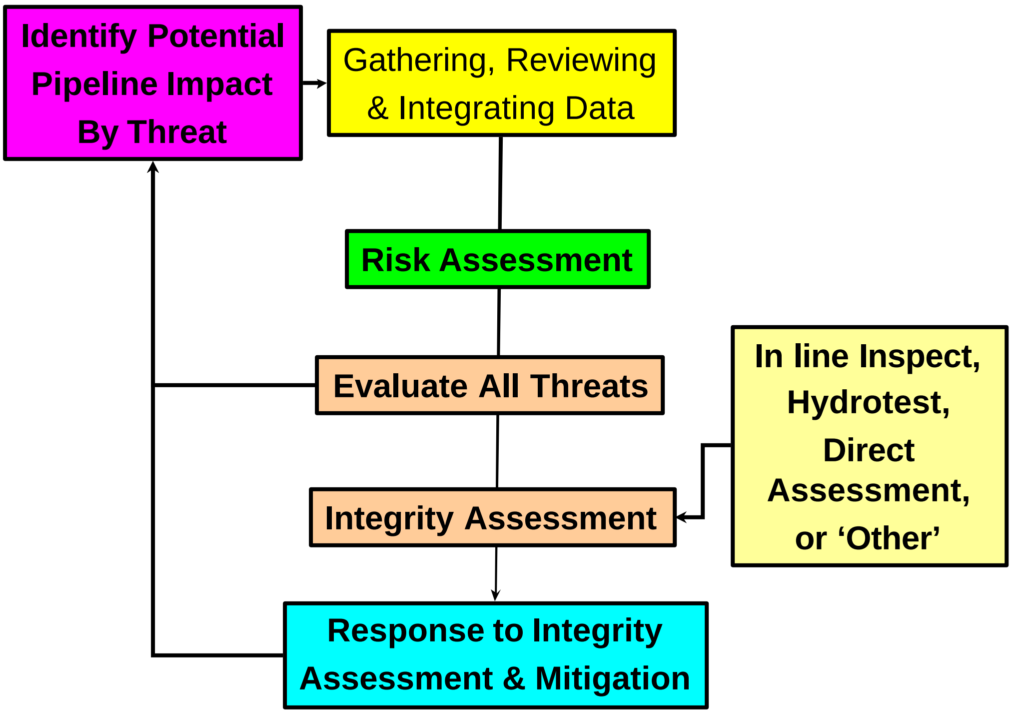

Figure 4. Integrity Management Plan Process Flow Diagram from ASME B31.8S.

Outside the USA, other countries also prefer qualitative risk analyses; for example, there is little use of quantitative risk assessments of Australian pipelines, due to lmited recorded pipeline incidents in the Australian industry database [11]. This limitation is considered a barrier to developing average failure rates for use in quantitative risk analysis.

4.4 Development of Pipeline Quantitative Risk Assessment (QRA) in the UK

Gas pipelines in the UK have historically been designed, constructed, and operated according to guidelines from the Institution of Gas Managers and Engineers: IGEM/TD/1 [12]. IGEM/TD/1 requires a pipeline 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 [13] (which has been developed progressively to the present day as PIPESAFE [1415].

The potential for the use of risk assessment in pipeline design was recognised in the British Standard Institution's pipeline standard BS 8010 Section 2.8 [16] and Edition 3 of IGE/TD/1 [17].

The TRANSPIRE and PIPESAFE packages were used to derive societal risk criteria based on the successful historical operation of UK pipelines using IGE/TD/1. They provided a consistent basis to support code infringements and to respond to land use planning issues. An outline of 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 in the UK [18], and is used at the design stage of major international pipeline projects.

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

3. 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 hydrocarbon pipelines including major accident hazard pipelines[4] (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.

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 IGE/TD/1 and PD 8010, which also included some general guidance on the use of QRA. UKOPA considered that risk supplements[5] to these two documents 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 use of risk analysis of pipelines with land use planning, in particular:

a Help with site-specific pipeline details; for example, the effect of increased wall thickness, pipeline protection (such as slabbing), depth of cover, damage type and failure mode.

b The effect of additional risk mitigation measures, which could be applied as part of the development.

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[4] A "major accident hazard pipeline" carries a “dangerous fluid” such as a fluid which is flammable in air and, or is to be, conveyed in the pipeline as a gas at above 8 bar absolute (see the UK’s Pipelines Safety Regulations 1996 for full descriptions). These fluids will include: natural gas; ethylene; spiked crude; ethane, propylene, LPG, etc.; and, NGL.

[5] IGEM/TD/2 is a separate but complimentary document to IGE/TD/1.

The availability of this formal 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 Land use planning (LUP) individual risk criteria.

The risk assessment supplements have been developed by the Risk Assessment Working Group (RAWG) of UKOPA over a period of three years. The supplements were published in 2009.

4. UK RISK ASSESSMENT GUIDELINES

4.1. Scope

The new supplements to IGEM/TD/1 (i.e. IGEM/TD/2) and PD 8010:2004 [45] 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.

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.

4.2. Applicable Substances

Dangerous fluids are defined in the UK's Pipelines Safety Regulations 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[6]:

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

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.

4.3. 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.

[6] Gasoline is expected to be included in 2010.

4.4. Event Trees

Both guidance documents present event trees for the release of both gases and liquids. **Figure 5** is an example for a heavier-than-air gas.

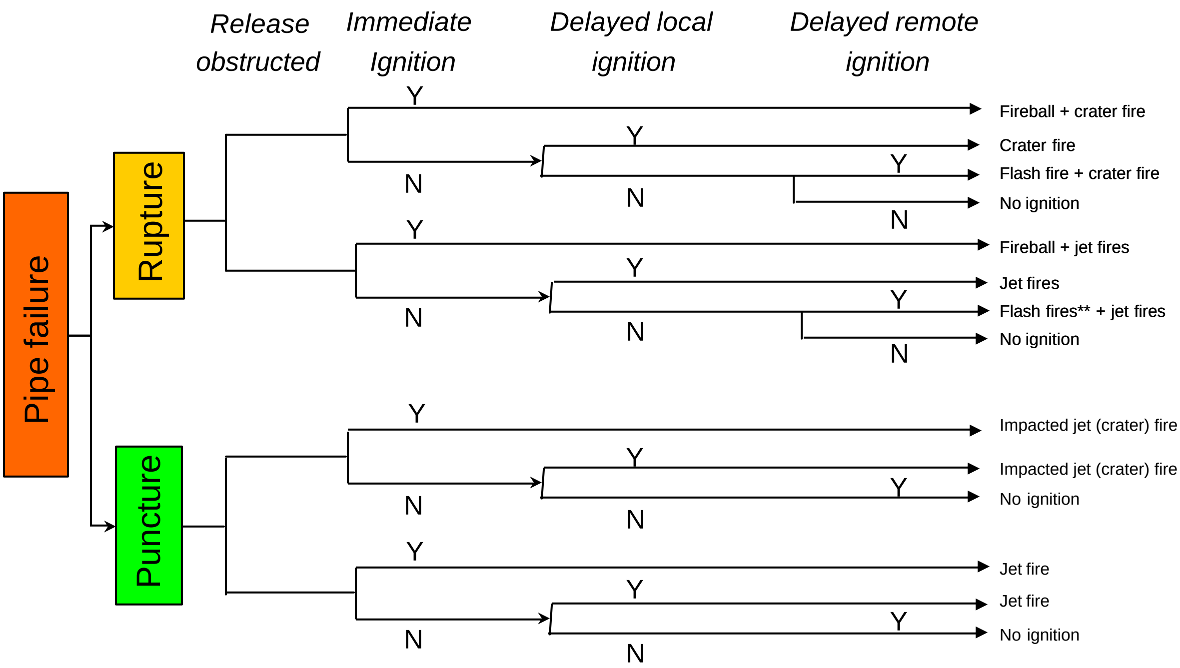

Figure 5. Event Tree for Heavier-than-air Gas [5].

4.5. Operational Fault and Failure Data

The two supplements recommend the use of recognised published operational data sources [192021] 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.**

Damage Mechanism	Pinhole	Hole	Rupture	Total
External ('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**

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

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 Cathodic Protection;
- regular in-line inspection; and,
- defect assessment and remedial action.

For pipelines commissioned pre-1980, it is recommended that the failure rates in **Table 1** should be applied unless corrosion control procedures (such as regular in line inspections) 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 a rupture failure due to corrosion in the UK.

Material and 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 natural 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 2.1×10^{-4} per 1000 km years is applicable to all UK major accident hazard pipelines, unless there is a local raised susceptibility..

4.6. Failure Frequency Prediction for External Interference

UK and European operational data on failures from external interference (usually caused by 3rd parties and resulting in punctures, gouges, dents or a combination of gouge and dent) 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 external interference 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 is shown in **Figure 6** below.

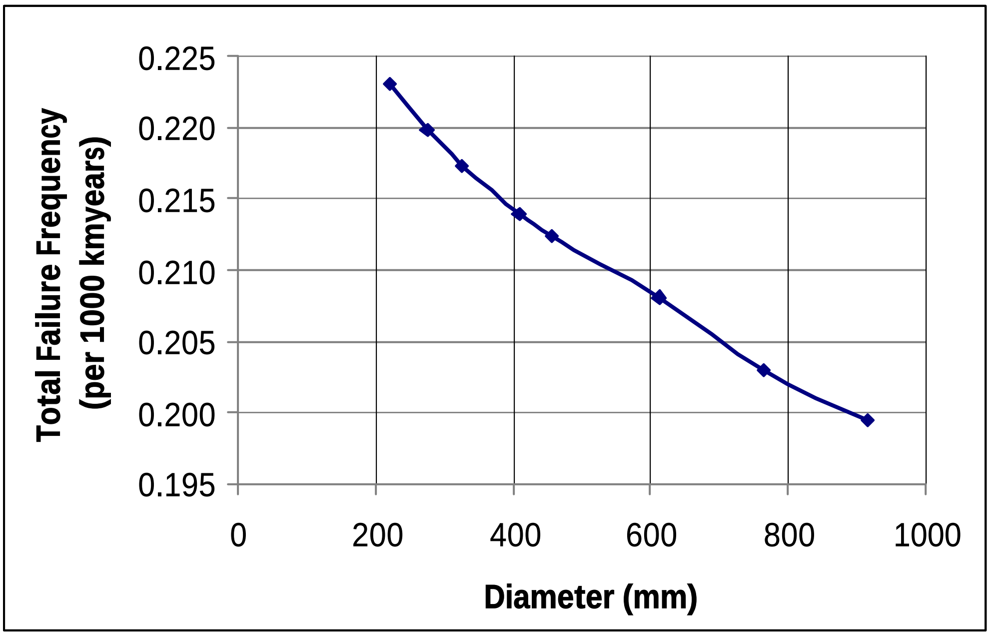

Figure 6. Generic Failure Frequency Curve for Estimation of Total Failure Frequency due to External Interference.

Failure Frequency Reduction Factors

Reduction factors for reduced design factors and wall thicknesses have been derived from comprehensive parametric studies, to allow the estimation of site-specific pipeline failure frequencies for external interference, [7].These factors should be applied to a nominal failure frequency which is dependent on pipeline diameter.

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 [24];
- Increased surveillance levels; and,
- Increased depth of cover [25].

Figure 7 gives examples of these reduction factors.

Use of Reduction Factors[7]

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.

[7] Refer to the supplements for the use and limitations in the application of these reduction factors.

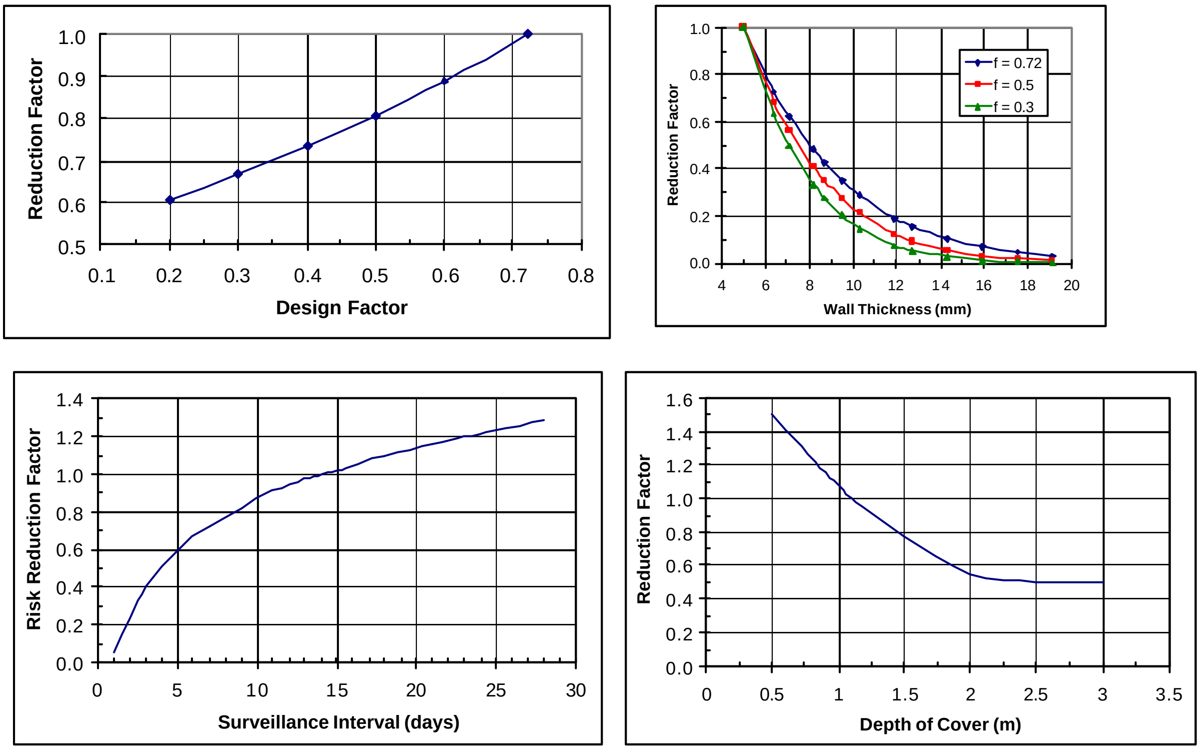

Figure 7. Reduction Factors in Supplements.

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 external interference and allow any developed prediction methodology to be benchmarked.

Table 2 gives sample calculations using the generic failure frequency curves and some reduction factors [8].

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

Table 2. Examples of Estimated Total Failure Frequency Calculations.

4.7. 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 30 seconds, and delayed ignition occurs after 30 seconds. Generic, product-specific values for ignition probability can be obtained from data from historical incidents [19, 20, 21] 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 daytime. 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 [26], which assumes a surface emissive power for the flame, or the point source method [26], 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 outdoors 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 outdoors 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 which is defined 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.

4.8. 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 8** [27, 28, 29].

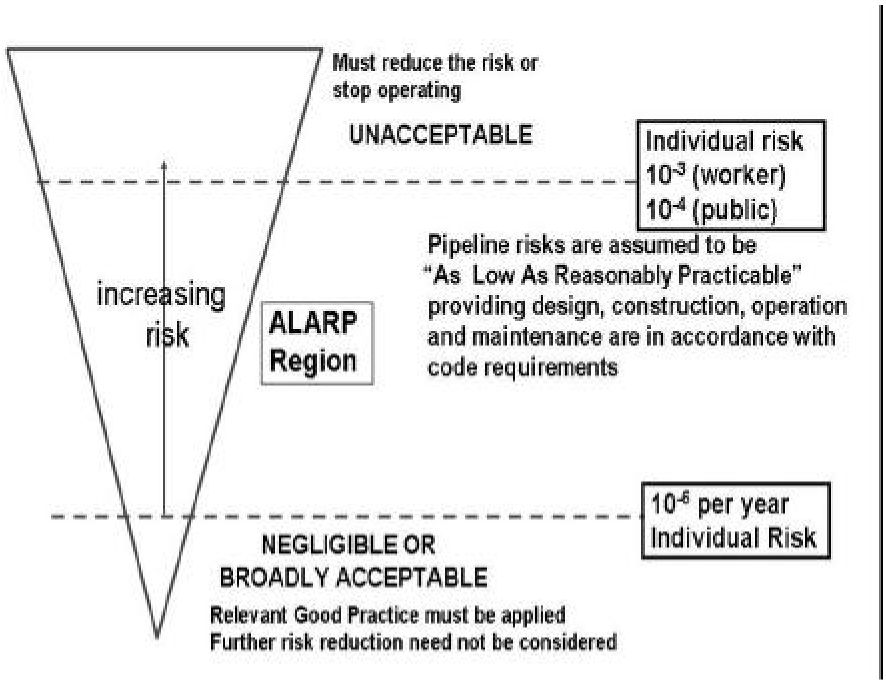

Figure 8. UK HSE Individual Risk Criteria.

These criteria can be used to assess the results of a QRA. **Figure 9** shows a QRA on a pipeline carrying jet fuel. The 'acceptable' risk is taken as 10^{-6}. This acceptable risk is exceeded close to the pipeline, but by adding protective measures such as a concrete slab over the pipeline, thicker pipe, pipeline marker tape, or an increase in the depth of cover, the risk can be reduced to an acceptable level.

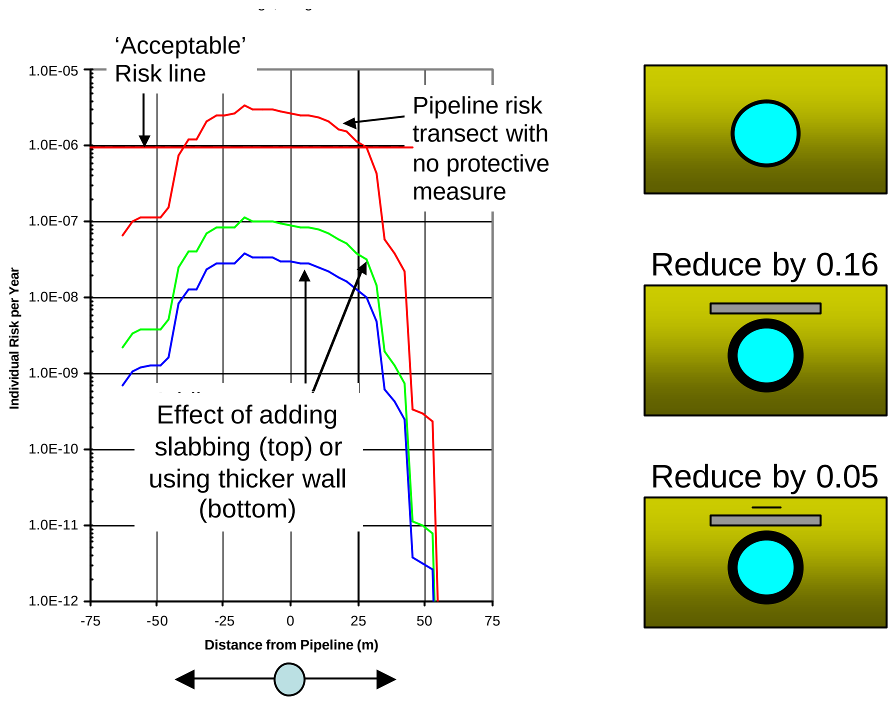

Figure 9. Example of a QRA on a Liquid Line, and Effect of Protective Measures.

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, **Figure 10**, and a similar curve has been developed for PD 8010 and pipelines carrying fluids other than natural gas.

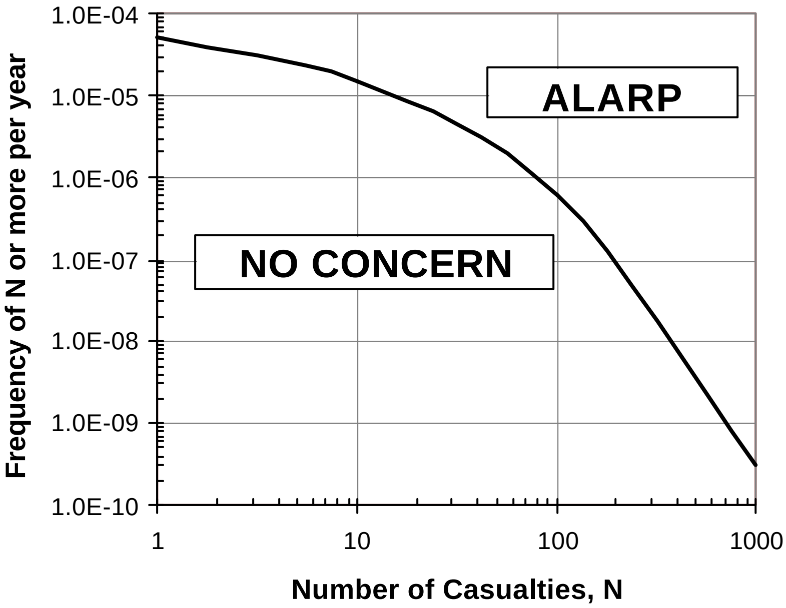

Figure 10. Sample FN Criterion.

5. CONCLUSIONS

UKOPA has helped produce pipeline risk assessment guidelines for the UK, and they are included in IGEM/TD/2 and BSI PD 8010-3. These documents provide authoritative and accepted guidance on risk analysis, including:

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

The guidelines are flexible, allowing more detailed approaches if required.

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