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Pipeline systems –

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 8010-1:2004

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Foreword

Publishing information

This part of PD 8010 is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on 1 January 2009. It was prepared by Subcommittee PSE/17/2, *Pipeline transportation systems*, under the authority of Technical Committee PSE/17, *Materials and equipment for petroleum*. A list of organizations represented on this committee can be obtained on request to its secretary.

Supersession

PD 8010-3:2009+A1:2013 supersedes PD 8010-3:2009, which is withdrawn.

Relationship with other publications

PD 8010-3 should be read in conjunction with PD 8010-1. The series comprises:

- Part 1: *Steel pipelines on land*;
- Part 2: *Subsea pipelines*;
- 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 8010-1:2004*;
- Part 4: *Steel pipelines on land and subsea pipelines – Code of practice for integrity management*.

A new part of the series, PD 8010-5, is in preparation.

Information about this document

This publication is not to be regarded as a British Standard.

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

The start and finish of text introduced or altered by Amendment No.1 is indicated in the text by tags **A1** **A1**. Minor editorial changes are not tagged.

Amendment A1 introduces the following principal changes:

- clarification on application criteria for ALARP assessment and land use planning;
- updates to slabbing protective measures and depth of cover;
- updates to HSE methodology;
- updates to UKOPA failure frequency data.

Use of this document

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

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

As with any risk assessment, judgement has to be employed by the risk assessor at all stages of the assessment. This part of PD 8010 is 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 is able to justify every key assumption made in the assessment and that these assumptions are documented as part of the assessment.

Presentational conventions

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

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

Contractual and legal considerations

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

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

Attention is particularly drawn to the Pipelines Safety Regulations 1996 [1] and to the requirements for risk assessments in UK health and safety legislation, in particular:

- the Health and Safety at Work etc Act 1974 [2];
- the Management of Health & Safety at Work Regulations 1992, amended 1999 [3].

Introduction

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

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

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

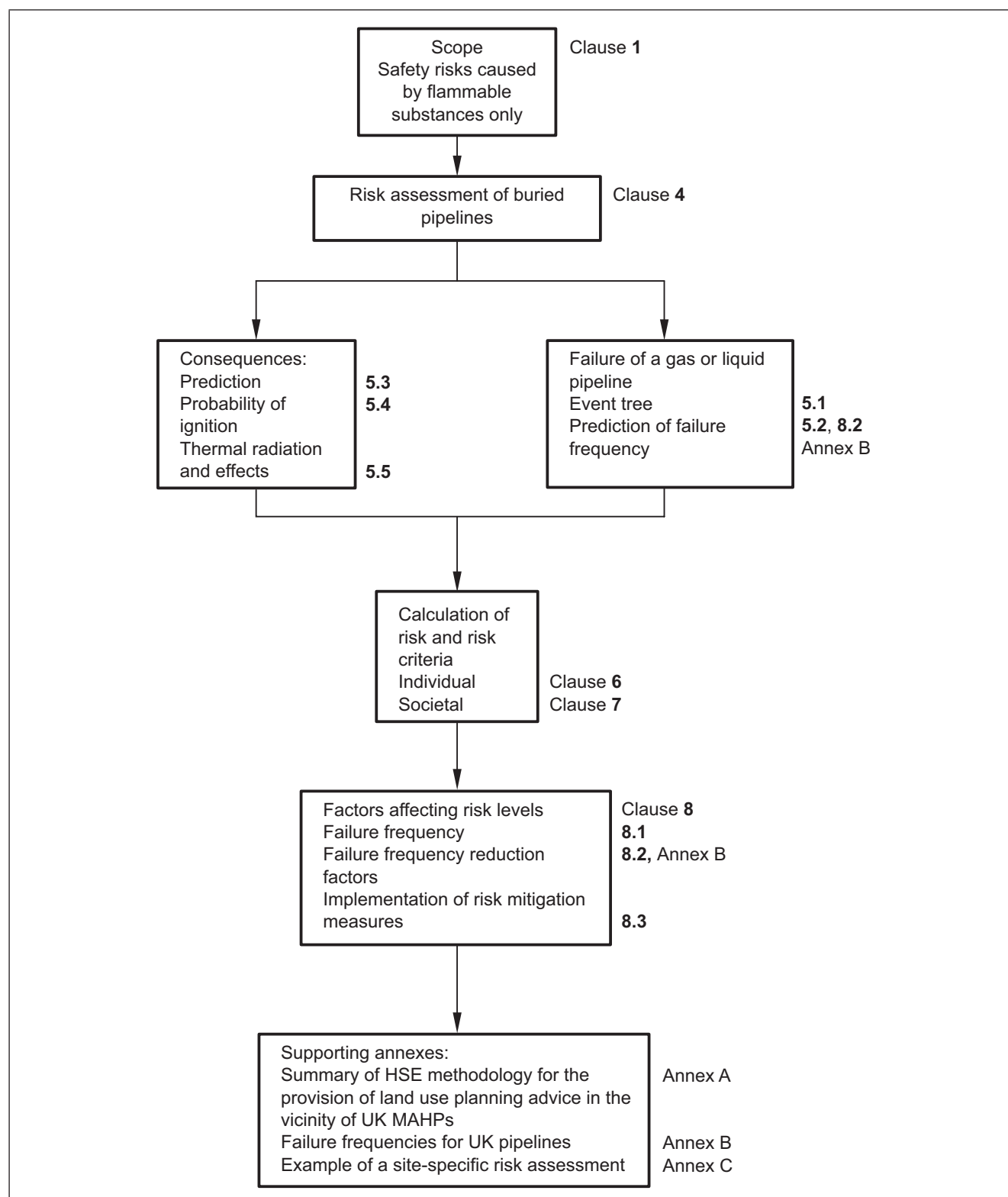
This part of PD 8010 provides guidance for the risk assessment of developments in the vicinity of major hazard pipelines containing flammable substances notified under the Pipelines Safety Regulations 1996 [1]. It does not cover toxic substances which are also notified under these Regulations. The guidance is specific to the calculation of safety risks posed to developments in the vicinity of UK major accident hazard pipelines, but the principles of the risk calculation are generally applicable. The use of such risk assessments to determine the acceptability of developments in accordance with land use planning applied in Great Britain is discussed in Annex A. The guidance does not cover environmental risks.

An overview of the document content is given in Figure 1.

The guidance in this part of PD 8010 is provided for the benefit of pipeline operators, local planning authorities, developers and any person involved in the risk assessment of developments in **A1** close proximity to **A1** existing major accident hazard pipelines. It is based on the established best practice methodology for pipeline risk assessment, and is intended to be applied by competent risk assessment practitioners.

For significant developments or infringements the pipeline operator might wish to carry out risk assessment using societal risk analysis for comparison with suitable risk criteria to allow the operator to assess whether the risks remain within acceptable limits. Clause 7 describes the application of societal risk, and includes a recommended *FN* criterion line.

Figure 1 Overview of PD 8010-3



1 Scope

This part of PD 8010 provides a recommended framework for carrying out an assessment of the acute safety risks associated with a major accident hazard pipeline (MAHP) containing flammable substances  as defined in the Pipelines Safety Regulations [1] . It provides guidance on the selection of pipeline failure frequencies and the modelling of failure consequences for the prediction of individual and societal risks.

The principles of this part of PD 8010 are based on best practice for the quantified risk analysis of new pipelines and existing pipelines. It is not intended to replace or duplicate existing risk analysis methodology, but is intended to support the application of the methodology and provide recommendations for its use.

This part of PD 8010 is applicable to buried pipelines on land that can be used to carry category D and category E substances that are hazardous by nature, being flammable and therefore liable to cause harm to persons. The guidance does not cover environmental risks.

2 Normative references

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

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

 UKOPA. *Specification – Impact protection slabs*. UKOPA/13/027. Ambergate, Derbyshire: UKOPA, 2013. 

3 Abbreviations

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

ALARP	as low as reasonably practicable
FFREQ	methodology recommended by UKOPA for prediction of pipeline failure frequencies due to external interference
HSE	Health and Safety Executive
LFG	liquefied flammable gases, including liquefied petroleum gases (LPG), liquefied natural gas (LNG), and natural gas liquids (NGL)
MAHP	major accident hazard pipeline
MAOP	maximum allowable operating pressure
MDOB	minimum distance to occupied building
PoF	probability of failure
SMYS	specified minimum yield strength
Tdu	thermal dose units

TS	tensile strength
UKOPA	United Kingdom Onshore Pipeline Operators Association
VCE	vapour cloud explosion

4 Risk assessment of buried pipelines – Overview

The failure of a pipeline containing a flammable substance (which can be a gas, a liquid, a dense-phase supercritical fluid or a two- or three-phase fluid) has the potential to cause serious damage to the surrounding population, property and the environment. Failure can occur due to a range of potential causes, including accidental damage, corrosion, fatigue and ground movement. The acute safety consequences of such a failure are primarily due to the thermal radiation from an ignited release, whether directly (from the main release) or indirectly (from secondary fires).

Quantified risk assessment applied to a pipeline involves the numerical estimation of risk by calculation resulting from the frequencies and consequences of a complete and representative set of credible accident scenarios.

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

- a) gathering data (pipeline and its location, meteorological conditions, physical properties of the substance, population) (5.1);
- b) prediction of the frequency of the failures to be considered in the assessment (5.2);
- c) prediction of the consequences for the various failure scenarios (5.3), including:
 - calculation of release flow rate;
 - estimation of dispersion of flammable vapours;
 - determination of ignition probability;
 - calculation of the thermal radiation emitted by fire in an ignited release;
 - quantification of the effects of thermal radiation on the surrounding population;
- d) calculation of risks and assessment against criteria:
 - estimation of individual risk (Clause 6);
 - estimation of societal risk (Clause 7);
- e) identification of site-specific risk reduction measures (Clause 8).

Pipeline failure frequency is usually expressed in failures per kilometre year or per 1 000 kilometre years (km·y). Failure frequency should be predicted using verified failure models and predictive methodologies [4, 5, 6, 7], or otherwise derived from historical incidents that have occurred in large populations of existing pipelines that are representative of the population under consideration, as recorded in recognized, published pipeline data. Various factors may then be taken into account for the specific pipeline design and operating conditions to obtain the failure rate to be applied.

NOTE Predictive models can be generated for all damage types and failure modes depending on the data available. In the UK, third-party interference is the dominant mode, and predictive models based on operational data are available [4, 5, 6, 7]. In general, failure frequency due to other damage types is derived using historical data [8, 9, 10].

The consequences of pipeline failures should be predicted using verified mathematical models, the results validated using experimental data at various scales up to full or comparison with recognized solutions, as well as comparison of model predictions with the recorded consequences of real incidents. The results of a consequence analysis should take into account all feasible events, in terms of the effect distance (radius) over which people are likely to become casualties. This should take into account people both outdoors and indoors.

Pipelines present an extended source of hazard, and can pose a risk to developments at different locations along their route. Where a length of pipeline over which a location-specific accident scenario could affect the population is associated with a specific development, the full length over which a pipeline failure could affect the population or part of the population should be taken into account in the risk assessment. This length is known as the interaction distance (see Clause 6 and Clause 7).

5 Failure of hazardous gas or liquid pipelines

5.1 General

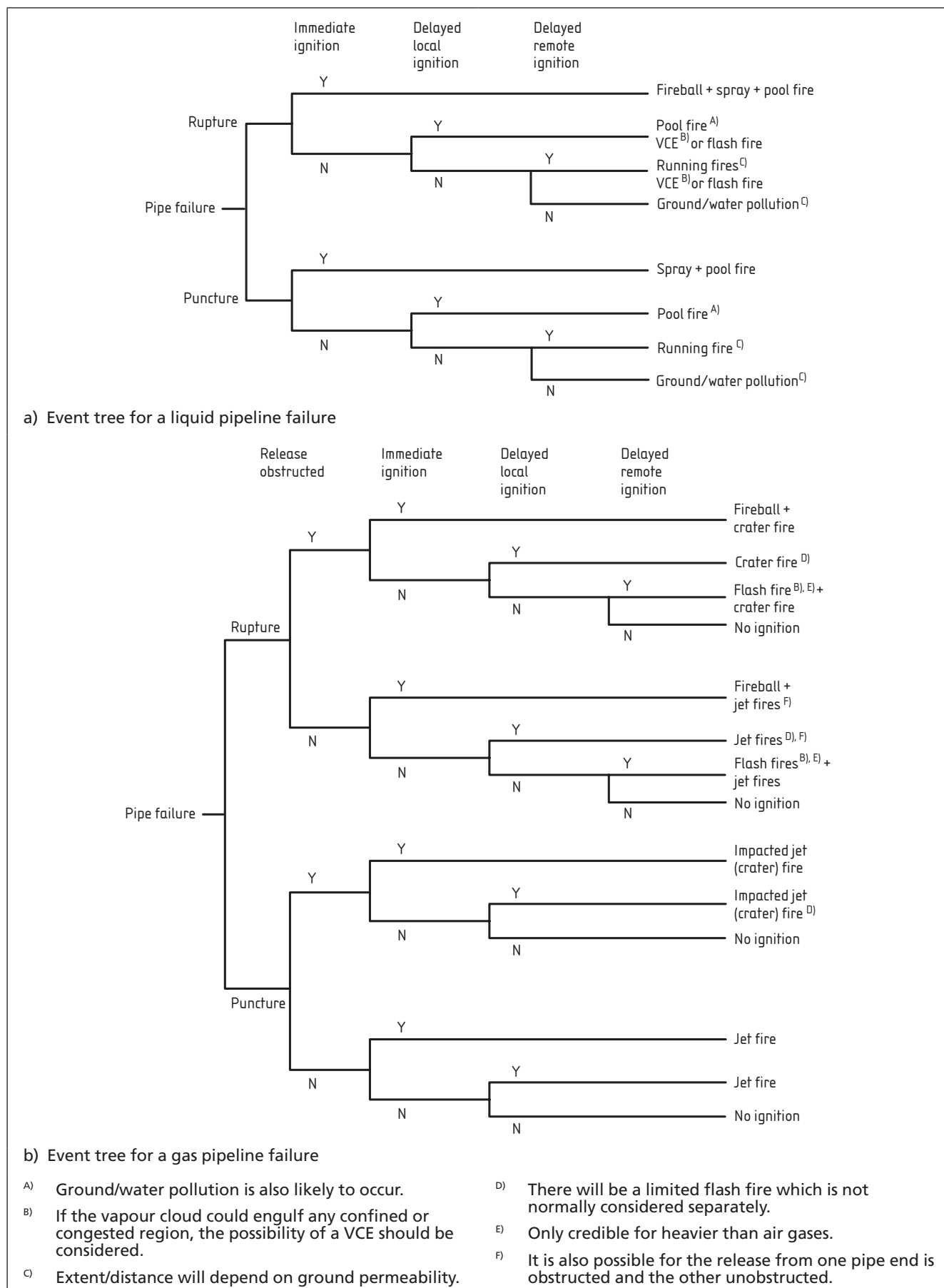
Failure of a hazardous gas or liquid pipeline has the potential to cause damage to the surrounding population, property and the environment. Failure can occur due to a range of potential causes, including accidental damage, corrosion, fatigue and ground movement. The consequences of failure are primarily due to the thermal radiation that is produced if the release ignites. This can be caused directly, or indirectly by igniting secondary fires. Illustrative event trees for the failure of a hazardous pipeline are shown in Figure 2.

NOTE 1 For detailed explanation of some of the consequence models which have been applied by HSE to derive existing Land Use Planning zones, see [11] to [14].

Failure of a high pressure pipeline can occur as a leak or rupture. Leaks are defined as fluid loss through a stable defect; ruptures are defined as fluid loss through an unstable defect which extends during failure, so the release area is normally equivalent to two open ends. The escaping fluid can ignite, resulting in a fireball, crater fire or jet fire which generates thermal radiation. Typical event trees for the failure of gas and liquid pipelines are shown in Figure 2.

NOTE 2 Spray fire is equivalent to a jet fire from a liquid line. Fireballs are technically not possible but vapour cloud explosions (VCEs) can occur where the liquid in the pipeline produces heavier-than-air vapour.

Figure 2 Event tree for the failure of a hazardous pipeline



For the assessment of a rupture release of a gaseous fluid, it is normally assumed that the ends of the failed pipe remain aligned in the crater and the jets of fluid interact. It is possible, e.g. at a location close to a bend or for a small diameter pipeline, for one or both pipe ends to become misaligned and produce one or two jets which are directed out of the crater and are unobstructed. Such releases can produce directional effects, making their assessment more complex. Where such a location or pipe is being assessed, the standard case would normally be assessed, then the sensitivity of the location to directional releases reviewed. A more detailed assessment might then be required which would go beyond the standard methodology described in this part of PD 8010.

NOTE 3 For large diameter pipelines (i.e. >300 mm), $\overline{A_1}$ the standard assumption is that the pipe ends are aligned $\overline{A_1}$.

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

For gases or vapours that are heavier than air, or form cold heavier-than-air gas clouds when released, the possibility of a flash fire or VCE should be taken into account. The extent of such gas clouds depends on prevailing weather conditions at the time of release, the location of possible sources of ignition, and areas of congestion or confinement. The modelling of the consequences and effects of VCEs are not discussed in detail in this part of PD 8010.

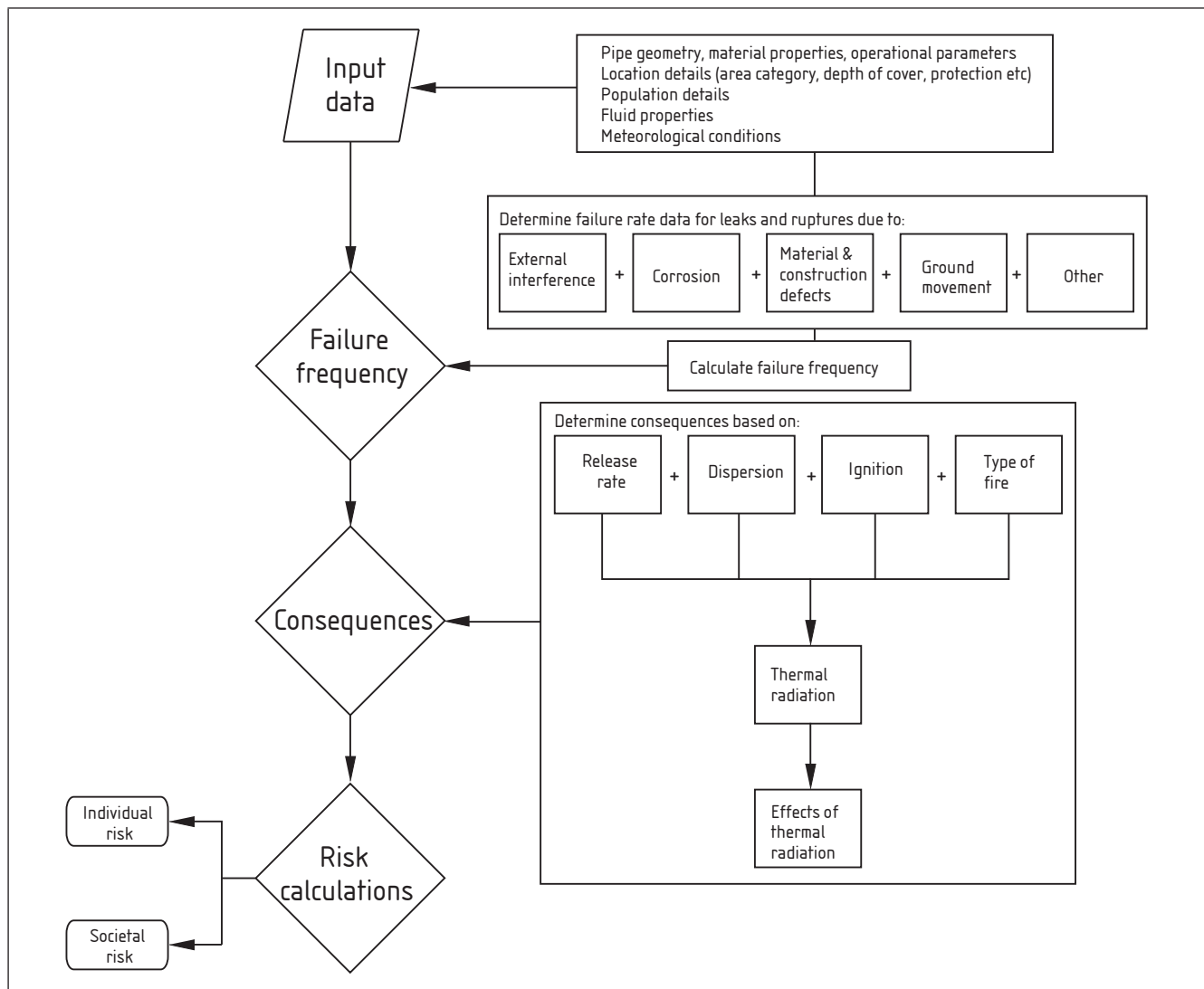
NOTE 4 In the case of natural gas, this scenario is not usually considered, as the release has a large momentum flux at the source and this normally has a significant vertical component. For the duration of the release relevant to the risk analysis, the transition to a low momentum (passive) release does not occur until the released natural gas has dispersed (is diluted) below the lower flammability limit.

The stages of pipeline risk assessment are represented in Figure 3.

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

- a) input of data (pipeline and its location, meteorological conditions, physical properties of the substance, population);
- b) prediction of failure mode and frequency;
- c) prediction of consequences:
 - calculation of release flow rate;
 - determination of ignition probability;
 - calculation of thermal radiation emitted by fire in an ignited release;
 - quantification of the effects of thermal radiation on the surrounding population;
- d) calculation of risks.

Figure 3 Risk calculation flowchart for flammable substances



The first stage of the risk assessment process is to gather the required data to characterize the pipeline, its contents and the surrounding environment. These data are used at various stages of the analysis. The data should be obtained from engineering records, operating data, the pipeline operating limits in the pipeline notification and an examination of the pipeline surroundings. The principal input data required for a pipeline quantified risk analysis are:

- pipeline geometry – outside diameter, wall thickness;
- pipeline material properties – e.g. grade (SMYS, TS), toughness (or Charpy impact value), and any other data required to apply a fracture mechanics model or to calculate the design factor;
- pipeline operational parameters – maximum allowable operating pressure, temperature, pipeline shutdown period A_1 and boundary conditions A_1 ;
- location details, including:
 - length and route of the pipeline to be assessed;
 - topographical information in any region of interest (e.g. ground slope direction, location of drainage channels and ditches);
 - location classification (class 1, class 2);

- depth of cover;
- additional protection measures for the pipeline (e.g. concrete slabbing);
- details of any above- and below-ground pipeline marking;
- development and building categories in the vicinity and their distance from the pipeline;
- population and occupancy levels within the consequence range of the pipeline;
- road/rail crossing details, including traffic density;
- river crossings;
- physical properties of the material being transported, including:
 - information to characterize the pressure, volume and temperature behaviour of the fluid throughout the range of conditions relevant to the analysis (e.g. from thermodynamic charts, tables or rigorous equations of state);
 - information to characterize any phase change within the fluid, e.g. from vapour to liquid (or vice versa), or to bound the dense phase region;
 - information about the density and viscosity of the fluid as a function of pressure, temperature;
- atmospheric conditions, for example:
 - details about ambient temperatures and pressures at the location of interest;
 - atmospheric humidity;
 - information about wind speeds and directions.

Any site-specific variations in the data should be assessed, and justifications for any additional assumptions to be applied locally should be documented. In the case of depth of cover, site-specific depths should be taken into account. Where additional pipeline protection such as slabbing is to be taken into account, the design and installation should be assessed to ensure that additional loading is not imposed upon the pipeline, and direct contact should be maintained between the pipe coating and the surrounding soil.

5.2 Prediction of failure frequency

Failure of a pipeline can occur due to a number of different causes such as:

- external interference;
- corrosion [internal and external, including stress corrosion cracking (SCC) and alternating current (AC)/direct current (DC) induced corrosion];
- material or construction defects;
- ground movement;
- other causes, such as fatigue, operational errors etc.

The failure modes that should be assessed include leaks of various sizes (punctures) and line breaks (ruptures). A key parameter in setting the boundary between a leak of a stable size and a rupture is the critical defect length.

The critical defect length is the axial length of a through-wall defect which becomes unstable at the specific pipeline conditions, and above which a defect will continue to propagate along the pipeline until the defect size becomes equivalent to a rupture. This is primarily dependent on the pipeline diameter, wall thickness, material properties, fluid properties (in particular the compressibility) and operating pressure. The critical defect length is significant for external interference, where long, narrow crack-like defects can occur. In such cases, the crack opening area through which the fluid release occurs is transposed into an equivalent hole size which can be used for release calculations. Typical critical hole sizes for high pressure gas pipelines are given in Annex B.

NOTE 1 Critical defect length and equivalent hole diameter applies to external interference where axial, crack-like defects can occur; the equivalent hole sizes which relate to such defects do not apply to rounded punctures, or stable holes due to corrosion or material and construction defects.

Leak sizes can range from pinholes up to a hole size equivalent to the critical defect size for the pipeline for external interference failures. A rupture release is typically represented by a full bore, double-ended break. The release is typically assumed to make a crater into which product is released from both ends of pipe.

Typical failure frequencies for UK MAHPs are given in Annex B. Where other data sources are used, these should be documented.

NOTE 2 In most cases the risk will be dominated by the rupture scenario.

NOTE 3 The maximum possible hole size in high pressure gas pipelines is limited according to the critical defect size.

In a risk assessment, the likelihood of each failure scenario is evaluated and expressed in terms of failure frequency and pipeline unit length.

5.3 Prediction of consequences

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

- outflow as a function of time (influenced by failure location, upstream and downstream boundary conditions, and by any response to the failure); pipeline rupture outflow requires complex calculations involving pressure reduction in the pipeline or two-phase flow for flashing liquids [15, 16]. Outflow from holes is calculated using conventional sharp-edged orifice equations for gas or liquid using a suitable discharge coefficient [13];
- thermal radiation from the initial and reducing flow into the fireball if the release is ignited immediately;
- thermal radiation from jet and crater fires. Jet fires that are unobstructed can have considerable jet momentum, resulting in a "lift-off" distance before the flame occurs, and therefore thermal radiation effects which can be greater in the middle and far field distance, depending on the release direction and degree

of wind tilt. Crater fires can be modelled as large cylindrical flames starting at ground level having thermal radiation effects progressively reducing through near, middle and far distance;

- extent of the area covered by a flammable gas cloud causing a possible flash fire downwind of the release, and possible ignition points in downwind areas;
- spillage rate and duration of release from a liquid pipeline affecting the local area and possibly causing a spray or pool fire.

Other consequences that are generally found to have a negligible effect on risk compared to fire effects include:

- release of pressure energy from the initial fractured section;
- pressure generated from combustion during the initial phase if the release is ignited immediately;
- missiles generated from overlying soil or from pipe fragments;

Additional aspects to be taken into account for pressurized liquid releases include:

- spray fires;
- immediate and delayed ignition pool fires;
- release of flammable liquids into water courses and the potential for running fires.

The consequence model should also take into account:

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

NOTE Weather category, as well as wind speed, also affects gas dispersion for flash fire prediction. In the UK, the conventional assumption is that night-time weather is modelled as Pasquill Category F and windspeed 2 m/s, and daytime as Category D and windspeed 5 m/s.

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

There is considerable evidence from actual events and research work that immediate ignition events involving sudden large releases of flammable gases can cause a fireball to occur. Typical fireball burn times are 10 s to 30 s depending on pipeline diameter and pressure. Large releases of liquefied flammable gases, and flammable liquids containing LFGs such as spiked crude oil, can also cause a fireball to occur.

When modelling either crater fires or unobstructed jet fires following a rupture, the transient nature of the release should be modelled. This calculation requires an estimate of the initial and steady state release rates and an estimate of the inventory of the pipeline network which is discharging to the release point. For generic calculations, the typical assumption made is that the break occurs half-way between compressor or pump stations (or pressure regulating station), with pressure being maintained from the upstream compressor, pump or

pressure reduction station and no reverse flow (with depressurization) occurring at the downstream check valve or regulator.

When modelling jet fires from punctures, the release can be considered to be steady state. The consequence model usually assumes a vertical wind-blown jet flame. More elaborate models are possible with different angles of flame. The consequences predicted by such models are increased directionally, but the conditional probability is reduced.

Flash fires occur when a plume of unignited heavier-than-air gas or vapour drifts 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, crater or pool fire. A vapour cloud can drift further in night-time conditions (category F2) than daytime (category D5). The probability of flash fires is considered low, being dependent on the release source and the distribution of ignition sources in the vicinity of a pipeline.

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

Spray releases occur when a flammable liquid is released at high velocity through a punctured pipeline.

5.4 Probability of ignition

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

It is usually assumed that immediate ignition occurs within 30 s, and delayed ignition occurs after 30 s. Generic values for ignition probability can be obtained from data from historical incidents and these are product-specific. The various ignition possibilities such as immediate, delayed and obstructed or unobstructed, are drawn out logically on an event tree (see Figure 2) to obtain overall probabilities.

Extensive references [12, 14,] are available for deriving probability of ignition for various situations (class 1, class 2, urban, roads, railways etc.). Probabilities used by HSE are discussed in Annex A.

5.5 Thermal radiation and effects

Fatal injury effects are assumed for cases where people in the open air or in buildings are located within the flame envelope. Outside the flame envelope, the effects are dependent on direct thermal radiation from the flame to the exposed person or building. Thermal radiation is calculated from the energy of the burning material. There are two main methods of calculation in use: the view factor method, which assumes a surface emissive power from the flame, and the point source method, which assumes that all the energy is emitted from one (or several) point sources within the flame. The energy from the fireball pulse is usually calculated using the view factor method.