Learning from Application of the CDOIF Environmental Risk Assessment Method to Major Accident Hazard Plant (Rev 3, 17/01/2020)

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The Chemical and Downstream Oil Industries Forum (CDOIF) guidance on assessment of tolerability of environmental risks was revised in 2016. This guidance provides a robust method for the assessment of potential environmental impacts from major accident hazards. This paper presents the learning from applying the CDOIF guidance at multiple UK oil sector installations. The approach can be used to demonstrate the integrity of existing infrastructure and demonstrate ALARP operating practices for pipelines and tank storage. It can also support investment decisions that are both protective of sensitive receptors and optimal for COMAH regulated operations.

Keywords: Environmental Risk, COMAH, CDOIF, Risk Assessment, MATTE, ALARP, QRA, Pipelines, Tanks, Sensitive Receptors

1. Introduction

The Chemical and Downstream Oil Industries Forum (CDOIF) guidance on assessment of tolerability of environmental risks was first published in 2013 and revised in 2016 (CDOIF, 2016). The CDOIF guidance and subsequent supporting guidance have brought significant clarity and consistency to the assessment of potential environmental impacts from major accident hazards. WSP's process safety and contaminate land teams have pioneered the application of the CDOIF guidance at multiple UK oil sector installations located in the vicinity of sensitive environmental receptors and the key learning is presented in this paper. Whilst this guidance has evolved to be ever more prescriptive, the framework of assessment should be viewed by the operators of COMAH facilities as an opportunity. CDOIF can be used to demonstrate the integrity of existing infrastructure and identify improvements in maintenance and operating practices. It can also build a robust case for intelligent future investment decisions that are both protective of the environmental and optimal for site operations.

The guidance was developed specifically for COMAH sites to provide a standardised framework for assessing the environmental consequences of a Major Accident Hazards (MAH), and to allow demonstration of as low as reasonably practicable (ALARP) measures to mitigate risk. The approach provides a screening process for assessment of major accidents to the environment (MATTE) and a method for equating impacts to individual receptors.

The CDOIF assessment process is analogous to that for assessing the risks to human health and safety under COMAH. Firstly, the CDOIF guidance requires the identification of relevant MATTE events for the installation such as releases of persistent, bio-accumulative or toxic substances that may lead to environmental damage (i.e. plant failures or accidents affecting groundwater, surface water, designated ecological systems, flora and fauna). Secondly, failure rate estimates or quantified risk assessment (QRA) for the frequency of these events are made taking account of different failure scenarios, equipment design and operation, maintenance and past failure incidents. Thirdly, the CDOIF guidance requires assessment of the likely severity of the impact on the selected environmental receptor(s) and the estimated duration for which the receptor may be affected (e.g. weeks, months, years). In complex installations, screening can be undertaken to shortlist the most significant scenarios to be taken forward to more detailed assessment using the CDOIF risk matrix. Normally the unmitigated frequency is assessed initially and then the benefit of mitigation measures such as secondary containment, alarms and emergency response, which reduced the duration or severity of the environmental harm are accounted for. Finally, the CDOIF grid allows the risk to be determined as tolerable, tolerable if ALARP or intolerable which in turn indicates what (if any) improvement actions are needed to ensure compliance with COMAH.

This paper provides an outline of the CDOIF guidance, its application and learning points from practical experience, including:

- Application at large, complex sites with multiple operations
- Screening diverse failure scenarios and estimating frequency of failure
- Multiple ways to impact the same environmental receptor
- Effectiveness of mitigation measures and emergency response

WSP accepts no responsibility for the application or interpretation of this paper by third parties. The opinions stated are the authors own views and the case studies presented are hypothetical examples based on practical experience of applying CDOIF guidance.

2. Regulatory Context

Major Accident Hazards and Major Accidents to the Environment (MATTEs) are regulated under the Control of Major Accident Hazards Regulations (COMAH, 2015). COMAH is designed to ensure that businesses take all necessary measures to prevent major accidents involving dangerous substances and limit the consequences to people *and the environment* of any major accidents which do occur. This paper focuses on assessing environmental risks and the methods used are a natural adaptation from those traditionally used to assess risks to people.

Under the COMAH Regulations all Upper Tier sites are required to submit a safety report to the Competent Authority (CA) that demonstrates the environmental risk for the whole site has been reduced to a tolerable levels (COMAH, 2015). Any Lower Tier site must prepare a risk assessment appropriate to the environmental risk, and whilst these are not required to be submitted to the CA these need to be available during site inspection and may be requested by the CA (which is the Environment Agency in England and Wales). In a COMAH report, it may be expected that the risk assessment for people and the environment are aligned in terms of scenarios that may lead to harm, frequencies and mitigating factors, but the nature of the receptors and level and duration of harm is obviously quite different.

All COMAH site operators are required to reduce risks to a level which is as low as reasonably practicable (ALARP). Consistent with the approach to safety-focused quantitative risk assessment, risks derived for MATTE scenarios are divided into three categories:

- Intolerable;
- Tolerable if ALARP (TifALARP); and
- Broadly Acceptable (or tolerable).

Under CDOIF, the determination of the risk level within three categories is a combination of both *potential level of harm* (covering MATTE categories A to D, with A being a minor short-term impact through to D being a major long-term impact) and *estimated frequency of occurrence* (from a very rare event frequency of <1 in 10 million years through to a likely event of >1 in 100 years), as shown in Figure 1 (the risk level of two hypothetical scenarios is marked with a X and Y).

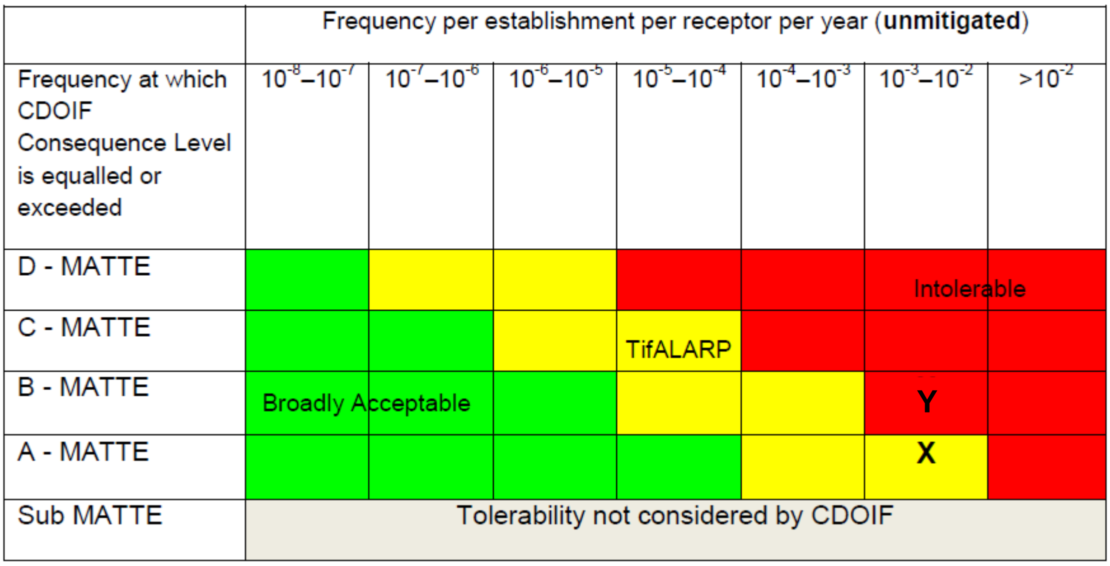

Figure 1. CDOIF Tolerability Grid (based on CDOIF, 2016)

It should be noted that even where a risk is assessed as broadly acceptable the COMAH regulations place a duty on operators to reduced risks as far as is reasonably practicable. ALARP determination does allow factors such as technical and economic feasibility to be considered (which would be the case for point X in Figure 1). However, if a risk is found to lie in the intolerable region (as with point Y in Figure 1), then technical and economic arguments are no longer valid and steps to reduce the risk must be implemented in the short-term, or operations must cease until the risk can be further mitigated, as summarised in Figure 2.

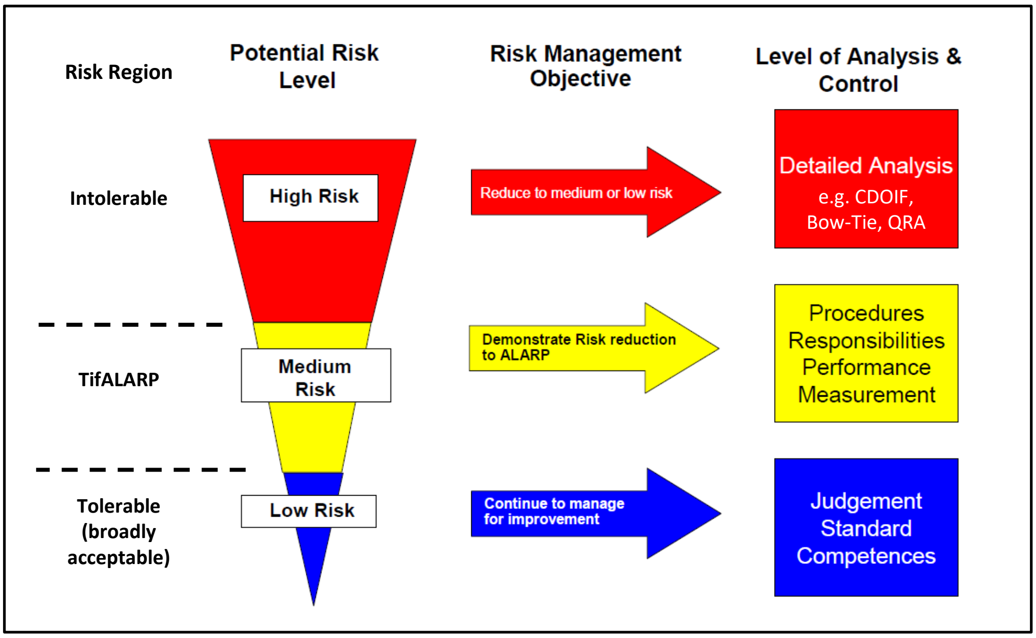

Figure 2 – Common framework for risk regions, objectives, analysis and control

The overall risk arising from all operations at the COMAH installation should be assessed. This will include all relevant MATTE events and all environmental receptors that could be significantly impacted, some of which may be up to 10 km distance from the site boundary. Since the guidance is relatively new, CDOIF assessments may be required by the CA as part of a wider site COMAH report update, or may be required as an improvement condition following a site incident or CA inspection.

3. CDOIF Guidance Overview

Provided below is a high-level summary of the CDOIF approach to assessment environmental risk tolerability. Since the issue of the most recent CDOIF guideline (2016) a number of supplementary guidance documents have been published to support the use of this methodology, most notably by the Energy Institute (EI, 2017).

Assessment Approach

The CODIF guidance uses a phased approach to the evaluation of MATTE risks, thereby allowing a larger number of possible scenarios to be narrowed do to those which may be most significant for overall installation risk levels, as follows:

- Phase 1A – MATTE Screen (all MAH scenarios)
- Phase 1B – Risk Screen (only scenarios which pass the MATTE screen)
- Phase 2 – Detailed Risk Assessment (most significant scenarios)

The default study area for MATTE assessment at a COMAH establishment is a 10 km radius (HSE & EA, 2010) around the site. This should be modified where pathways exist that may preferentially result in impact to receptors outside of this radius, for example the presence of a tidal estuary. The three phases include the following assessments:

Phase 1A

A *qualitative* consideration, based on conservative assumptions, of possible MATTE scenarios through review of the available sources within an establishment, potential migration pathways and environmental rectors within the defined study area. Potential MATTE impacts can be screened out at this stage where no source-pathway-receptor (S-P-R) linkage is present. Credibility of potential S-P-R linkages is evaluated further in Phase 1B.

Phase 1B

A *qualitative or semi-quantitative* analysis of identified MATTE scenarios (S-P-R linkages), undertaken with reduced conservatism relative to Phase 1A. Risks that can be assessed as broadly acceptable at this screening stage can be discounted from more detailed evaluation in Phase 2.

Phase 2

A *semi-quantitative or quantitative* assessment of the remaining significant MATTE scenarios to evaluate risk and tolerability levels. In keeping with established QRA approaches, the effort put into risk assessment should be proportionate to the scale of the risk being considered. For COMAH regulated sites, especially Upper Tier establishments, MATTE consequences are potentially significant and will require detailed modelling and assessment.

Environmental Receptors

The starting point for any MATTE assessment is understanding the environmental receptors in proximity to an establishment and how these can be impacted. Once these linkages have been identified the relevant prescribed MATTE thresholds can be assigned to each receptor.

Receptors are grouped depending on their nature (groundwater, surface water, designated ecological systems) and subsequently their level of importance. For example there are different thresholds for internationally designated ecological systems (such as RAMSAR sites) compared with nationally designated ecological systems (such as SSSI). In the case of aquifers and groundwater resources, distinction is made between groundwater used for potable public supply and all other groundwater resources. The CDOIF guidance (2016) provides a number of resources from which to obtain this information for sites in the UK.

The lower thresholds for 'Major' impact to an Environmental receptor have been in place for over 20 years having first been formally collated in the late 1990s (DETR, 1999). The CDOIF guideline further refined the MATTE impact scale by introducing four categories of MATTE impact, recognising that there is a very wide range of potential consequence that can be considered a MATTE (c.f. a diesel spill that impacts 0.5 ha of a SSSI, compared with a large marine release such as the Deepwater Horizon event). An example of what constitutes a MATTE for three environmental receptor groups is given in Table 1, more detailed tables are available in the guidance (CDOIF, 2016).

Freshwater and estuarine habitats (water)	**Marine (water)**	**Particular species (land, water, air)**
The level of harm that would constitute a MATTE is defined as follows:	The level of harm that would constitute a MATTE is defined as follows:	The level of harm that would constitute a MATTE is defined as follows:
The chemical or ecological status given by the Water Framework Directive (WFD) has been lowered by one class for more than 2 km of a watercourse	2 ha or more of contamination to the littoral or sub-littoral zone	1% or more of the population
10% or greater of the area (for estuaries and ponds, reservoirs and lakes)	100 ha or more of open sea benthic community	5% or more of the plant ground cover
2 ha or more of the area for estuaries or ponds, reservoirs and lakes	100 or more dead sea birds (500 or more gulls)	
Interruption of public or private drinking water supply, where: (persons affected x duration in hours {at least two hours}) > 1,000	5 or more dead/significantly impaired sea mammals	Note: the 1% and 5% above refer to national populations of England, Wales or Scotland. May be lower thresholds for particular high value or special protection species.

Table 1. Levels of Harm that Constitute a MATTE (based on CDOIF, 2016)

Evaluating Risks and Tolerability

The four categories of MATTE impact (A-D) are calculated through a combination of the extent (severity score 1 to 4) and recovery period (duration score 1 to 4) associated with the modelled impact from a MAH scenario. Prescribed thresholds for severity and duration classification are provided in the CDOIF guideline (2016) as exemplified in Figure 3. Further supporting guidance of the assignment of duration categories has subsequently been published by the Energy Institute (Energy Institute, 2017).

Receptor Type	Severity of Harm			
	Significant *While this level of harm might be significant pollution, it is not considered a MATTE.*	**Severe** *DETR Criteria - the lowest level of harm that might be considered MATTE.*	**Major**	**Catastrophic**
Severity Level →	1	2	3	4
Fresh and estuarine water habitats	Impact below that of Severity level 2	WFD Chemical or ecological status lowered by one class for 2-10km of watercourse or 2-20ha or 10-50% area of estuaries or ponds. Plus interruption of drinking water supplies, as per DETR Table 6	WFD Chemical or ecological status lowered by one class for 10-200km of watercourse or 20-200ha or 50-90% area of estuaries and ponds. Plus interruption of drinking water supplies, as per DETR Table 6	WFD Chemical or ecological status lowered by one class for >200km of watercourse or >200ha or >90% area of estuaries and ponds. Plus interruption of drinking water supplies, as per DETR Table 6

Description	Short term	Medium term	Long term	Very long term
	Harm with such short recovery is not considered a MATTE.			
Harm Duration Category →	1	2	3	4
Groundwater or surface water drinking water source (public or private)			Harm affecting drinking water source or SPZ < 6 years	Harm affecting drinking water source or SPZ >6 years

Figure 3. Examples of MATTE harm severity and harm duration scoring (reproduced from CDOIF, 2016)

The MATTE categories set out in the CDOIF methodology allow operators to equate the relative importance of impacts to environmental receptors of differing nature. Operators are required to assess the overall MATTE risks from each installation as a whole. This is done by summation of the frequencies modelled for potential MATTE impacts to each receptor. For higher consequence MATTE categories, the frequency applied is the sum of all potential MATTE impacts of that magnitude to a given receptor plus the frequency of all lower category MATTE impacts to that same receptor (for example fC = fC +fB + fA). For each class of MATTE impact, a different tolerability scale is applied, as summarised in Figure 1.

Severity of Harm					
	4		C	D	D
	3		B	C	D
	2		A	B	C
	1	*Sub-MATTE Harm*			
		1	2	3	4
		Harm Duration Category			

Frequency at which the CDOIF consequence level is reached or exceeded	Frequency per receptor per establishment per year	
	Intolerable (greater than)	Broadly Acceptable (less than)
A	1.0 E-02	1.0 E-04
B	1.0 E-03	1.0 E-05
C	1.0 E-04	1.0 E-06
D	1.0 E-05	1.0 E-07

Figure 4. MATTE Category Derivation and Tolerability (based on CDOIF, 2016)

Risks which lie between the intolerable and broadly acceptable boundaries are classified as tolerable if ALARP. For these risks a demonstration of why risks are considered to have been reduced to an ALARP level is required. For example, with a MATTE category B event (e.g. a small oil spill affecting a sensitive marine receptor over the long term), a frequency of 1 > 1,000 years is intolerable and a frequency of <1 in 100,000 years is broadly acceptable, with anything in-between being TifALARP. At the highest end of severity, it is unusual to identify a category D MATTE event in UK operations as that would also likely represent a catastrophic MAH for people which would give an intolerable risk, thus preventing a COMAH permit (and an Environmental permit) being issued or renewed by the Competent Authority. At the lowest end of severity, category A MATTE events are less relevant in terms of total site risk tolerability (unless they have high frequency). Thus the overall site risk tolerability assessment is likely to focus on category B and C MATTE events which do not have a very low frequency, and for which ALARP risk reduction must be demonstrated.

When evaluating risks operators should first assess the unmitigated probability of all MATTE scenarios and assess the establishment risk in this unmitigated case. Following this initial assessment the actual (or mitigated) scenarios should be assessed and the mitigated establishment risk derived. Awareness of the variance in tolerability between the unmitigated and mitigated cases can illustrate the importance of the maintenance and successful deployment on demand of layers of protection for any given MATTE scenario.

ALARP Demonstration

When preparing an ALARP demonstration, the focus often narrows immediately to a cost-benefit analysis (CBA). A sound ALARP demonstration should, however, contain far more than merely this numerical comparison. The establishment risk approach allows operators to focus future investments in areas where they will yield the highest benefit. As part of the demonstration operators should:

1. Demonstrate their compliance with best practice
2. Identify all existing layers of protection relevant to a potential Major Accident Scenario
3. Analyse costs and benefits (quantitative and qualitative) associated with potential additional mitigation measures

The first two items above provide operators with an opportunity which is often missed, to demonstrate the range safety systems and processes in place as well as the integrity of infrastructure which has often been installed at significant cost. For the third item, the costs of plant upgrade or new maintenance procedures may be known but it may not be possible to quantify all of the key environmental benefits and so qualitative assessment may also be included.

When approaching cost-benefit comparison the CDOIF guideline (2016) sets out a scope of items that should be included in the quantification of the benefit associated with any further mitigation measures. In the case of a MATTE, the main benefit is often the avoidance of costs associated with clean-up of the MATTE scenario should it materialise.

The cost-benefit approach put forward by CDOIF aligns with the HSE approach for safety cases. The challenge comes in putting a value on the benefit that can be agreed with the Competent Authority. Factors that will contribute to the benefit, are the costs that would be entailed in the event of the MATTE scenario, items such as clean up and restoration of surface water and habitats, remediation of soils and groundwater, replenishment of fish stocks, and ongoing monitoring.

There are multiple sources of published information relating to the financial impacts of previous environmental incidents and CDOIF guidance provides references to some useful accident databases (2016). However, the applicability of case studies to different sites and different receptors requires careful consideration, particularly in coastal areas or where a SSSI or aquifer is present.

In the previous example in Figure 1, if the overall site risk were to lie at point X in the tolerable if ALARP region then the operator could use CBA to justify the use or non-use of further mitigation measures to reduce the risk levels (arguments of disproportionate costs may be considered). Health, safety and environmental benefits (or avoided environmental damage costs) should be included in the CBA, but business benefits such as avoided loss of production, lower insurance premiums are to be excluded from the CBA. If a CDOIF assessment finds an 'intolerable' risk (as with point Y in Figure 1) then the operator is duty bound to act upon this without delay to reduce the risk. In this context the CDOIF guidance (2016) notes that:

> "*If the risk to a receptor is intolerable then the operator is expected to reduce the risk to an acceptable level almost irrespective of the costs (CBA as outlined here does not apply).*"

It is noted that it is entirely possible that a MAH scenario which gives a tolerable rating for people may give an intolerable rating for environment, and vice-versa. The CDOIF tolerability grid should be used as a guide to identifying those scenarios which appear to lie at the boundary of the three categories (particularly those close to the intolerable region), and therefore can be used to focus further efforts on addressing the most significant risks for the environment using ALARP demonstration.

Further guidance is available in the Competent Agency's 'All Measures Necessary Guidance' which provides information relating to the risk reduction provided by different prevention and mitigation layers (HSE & EA, 2016).

4. Oil Pipeline Case Study

WSP has undertaken CDOIF risk assessments for various oil terminals and refineries in the UK and the example below outlines the approach and key issues in the case of a transfer pipeline which had suffered historical corrosion.

Regulatory Context

Pipelines are of particular interest for application of the new CDOIF risk assessment methods. Strictly pipelines are only covered by COMAH where they exist within the regulated site boundary, but clearly they can give rise to MATTE events along their entire length where they transfer feedstock or product over longer distances beyond the site boundary.

Under the 1996 Pipeline Safety Regulations (PSR, 1996) the operator of a pipeline, has a duty under those Regulations to ensure the safe operation and to ensure that the pipeline is maintained in an efficient state, in efficient working order and in good repair. The operator also has a duty to ensure that the pipeline is decommissioned safely in accordance with the Regulations when operation ceases. The Regulations do not cover the environmental aspects of accidents arising from pipelines. However the Regulations, by ensuring that a pipeline is designed, constructed and operated safely, provide a means of securing pipeline integrity, thereby reducing risks to the environment. To this effect the Preface to the HSE guidance note on the Pipeline Safety Regulations 1996 (HSE, 1996) briefly states that:

"*The Pipelines Safety Regulations 1996, made under the Health and Safety at Work etc Act 1974, do not cover the environmental aspects of accidents arising from pipelines. However the Regulations, by ensuring that a pipeline is designed, constructed and operated safely, provide a means of securing pipeline integrity, thereby reducing risks to the environment. It is important that effects on the environment are considered at all stages in the life cycle of a pipeline.*"

It is also noted that The Pipelines Act 1962 covers cross-country pipeline greater than 16 km in length and which require government authorisation. The Pressure Systems Safety Regulations 2000 covers only pipelines which carry gases or liquefied gases within the definition of relevant fluid. Similarly, pipelines are excluded from the Pressure Equipment Regulations 1999 which implement the Pressure Equipment Directive 97/23/EC.

The UK Onshore Pipeline Operators' Association (UKOPA, 2014) provides guidance on best practices for monitoring pipeline safety. These are based on a number of indicators and form part of a risk based safety management systems (SMS). They note corrosion as a key leading indicator of pipeline integrity.

Pipeline inspection reports from pigging runs or other non-destructive testing for do not constitute a risk assessment, they simply report the extent of corrosion on the day of inspection and state the mechanical condition of the pipeline. They compare the remaining metal wall thickness against theoretical stress calculations to determine if under ideal conditions the pipeline can withstand its maximum rated operating pressure (MAOP). The stress calculations assume static pressure and temperature which do not reflect the dynamics of actual pipeline operation, or other deviations such as those that may be identified by HAZOP. Passing the MAOP 'test' does not guarantee that the pipeline will not fail prior to the next inspection date. Thus, it is argued that a more formal risk assessment method such as CDOIF is applicable to such pipelines, including those that extend beyond the COMAH site boundary and have a potential to give rise to MATTE events.

Pipeline Example

In the example shown in Figure 5, both the Oil Terminal A where crude oil Pipeline Z begins and Refinery B where the pipeline ends are classified as COMAH installations (upper tier) as they meet the criteria of a Major Accident Hazard (MAH). Certain lengths of the pipeline and the tanks are located within these site boundaries and are covered by COMAH. However, the majority of the pipeline length which lies outside these site boundaries is not covered by COMAH, and is instead covered by the Pipeline Safety Regulations 1996. Pipeline Z is 10 km in length and 12" NB running both above and below ground, passing through numerous different landowner boundaries in close proximity to housing, sensitive habitats, watercourses and groundwater sources.

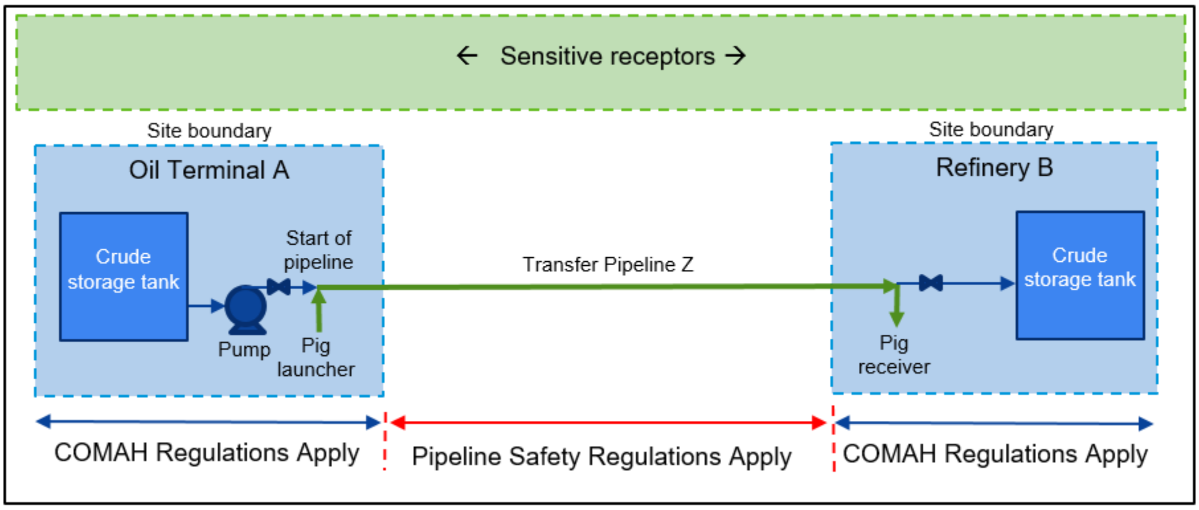

Figure 5. Example of a refinery transfer pipeline and applicable regulations

The Pipeline Safety Regulations 1996 define the pipeline start as the location of the pig launcher and the pipeline end as the location of the pig receiver. The Regulations do not classify Pipeline Z as a MAH pipeline as the relevant HSE guidance note provides an exemption from the MAH criteria for stabilised crude oils. In this context the MAH pipeline designation is reserved for "dangerous fluids" carried in cross-country pipelines such as flammable or explosive gases. The requirement to ensure safe operation applies to non-MAH pipelines which lie outside the boundary of an industrial site. However, a number of more stringent safety requirements are placed upon MAH pipelines.

Whilst Pipeline Z does not technically meet the criteria of a MAH under either COMAH or the 1996 Pipeline Safety Regulations (which are predominantly focused on protecting human health and safety), the pipeline operation has features which could give rise to a MATTE event, which if such occurred could foreseeably lead to one or more of: significant harm to a nearby SSSI; groundwater contamination; sea bird and fish deaths; regional economic losses; prosecution by the Environment Agency; and/or, other civil claims. The fact that a pipeline at some point leaves a COMAH site boundary should not change the responsibility that the operator has to assess the overall risks from pipeline operation, including MAHs and MATTEs.

In this example, historical corrosion and damage to sections of the pipeline further indicate the need for a full risk assessment. The latest pigging runs suggest that corrosion rates are accelerating and indicate a possible breakdown of the protective coating in some sections, with pitting up to 70% of wall thickness in some isolate areas.

CDOIF Assessment

Following the CDOIF guidance (2016), a risk assessment was undertaken for Pipeline Z and included the following steps:

1. High-level review of available pipeline operational and inspection data
2. Review of previous reports including HAZOP findings (for other failure modes)
3. High-level assessment of pipeline failure risk and potential consequences (indicating significant concern).
4. Identification of relevant environmental receptors within 10 km (focus on SSSI and groundwater)
5. Identification of potential MATTE scenarios (based on existing site COMAH report)
6. High level assessment of MATTE consequences (severity and duration using CDOIF tables)
7. Focus on the two most significant scenarios (gradual leak underground and large above ground leak due to corrosion)
8. Confirmation of CDOF risk level for these two scenarios (one of which was intolerable)
9. Identification of further risk reduction measures required (to allow ongoing operation)

In this case, the MATTE screening assessment identified two significant scenarios – one for a major pipeline failure due to rapid corrosion (i.e. a large volume release that can identified quickly through pressure monitoring) and one for a minor failure due to more gradual corrosion (which is sufficiently small in release rate to go undetected). Review of the pipeline inspection and COMAH reports provided useful data to assess the potential release volume and duration, giving a MATTE severity. For frequency of the two events, benchmark failure rates were obtained from published industry figures, as shown in Table 2 and Figure 6.

Data source	Years covered	Failure Frequency (per km.year)	Notes
UKOPA, 2015	1965-2015	2.63E-04	Long-term average, all UK onshore oil and gas pipelines
UKOPA, 2015	1995-2015	7.40E-05	Based on 23,000 km of all types/sizes of UK pipeline
OGP, 2014	1971-2000	8.00E-04	For 8" to 12" NB onshore oil pipeline, European data
USDOT, 2010	2005-2009	2.25E-04	Based on 260,000 km of US hazardous liquid pipelines
USPST, 2015	2005-2014	4.38E-05	US data covering onshore hazardous liquid pipelines

Table 2. Selected Industry Data on Pipeline Failure Rates

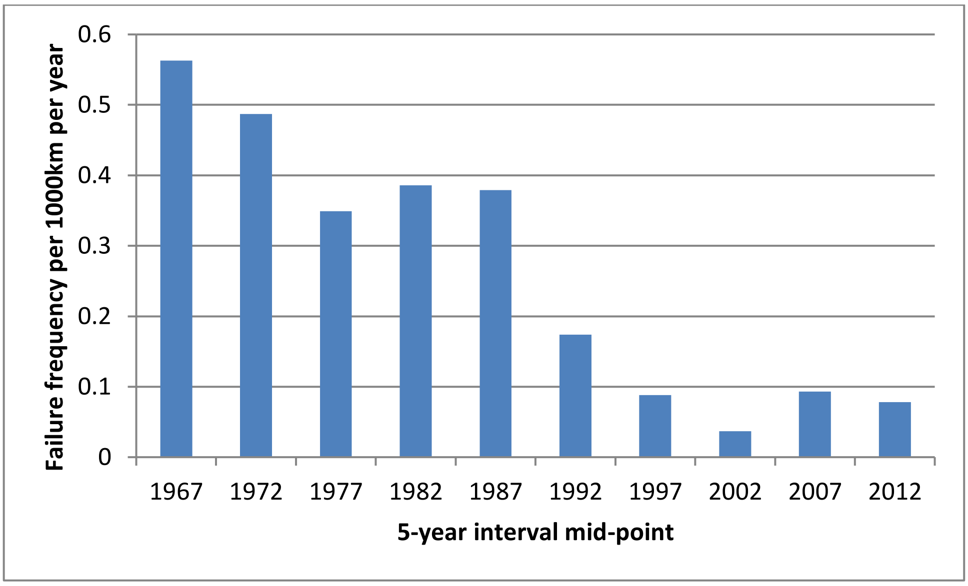

Figure 6. UK Onshore Pipeline Historical Failure Rates (UKOPA, 2015)

The above failure frequencies range from 4 * 10^{-5} to 8 *10^{-4} /km/year and this 20-fold range indicates the expected variability in statistical pipeline failure data covering a range of different datasets. For the purposes of the Pipeline Z assessment the most appropriate comparable failure rate was judged to be the value of 7.40 *10^{-5} /km/year from UKOPA (i.e. the 1995-2015 dataset for UK onshore pipelines corresponding to the period since the Pipelines Safety Regulations were in force). It is noted that this value rounds to 1 * 10^{-4} /km/year or an expected failure once in every 10,000 years for each km of pipeline.

Thus for Pipeline Z, based on its 10 km length and the comparable industry average failure rate of 7.40 *10^{-5} /km/year from UKOPA, a total failure rate of 7.4 *10^{-4} per year can be estimated. However, given that Pipeline Z has active and significant external corrosion and repairs being needed, it is considered that a minimum 10-fold increase in failure rate above the industry average would apply in this case. Based on current knowledge of the pipeline and review of corrosion data, it was therefore considered that the Pipeline Z failure rate could be in the 10^{-2} to 10^{-3} per year range on the CDOIF grid (unmitigated) for further risk assessment purposes.

Hypothetical release scenarios for Pipeline Z were considered for both pumping and hydrostatic heads, for hole diameters of 10mm and 100mm. Calculated leakage rates (based on a hypothetical crude oil release) ranged from 4 m^3/hr – 12 m^3/hr for a 10mm hole (for hydrostatic and pumping pressures respectively). For the larger 100mm hole size, leakage rates were calculated to range between 350 and 1300 m^3/hr. The duration of release until it was detected and brought under control was considered to be >24 hours for a small hole and 0.5 hours for a larger hole. These various scenarios lead to estimates of anything from 10 tonne of product up to 600 tonnes of product being released in total.

Based on high level review of GIS data and publicly available information on local receptors within 10km of Pipeline Z, potential MATTE classifications for the principal receptors were anticipated to be:

- Nearby SSSI affected by large above-ground release – MATTE **Category C** (based on the potential to impact >50% of SSSI areas)
- Groundwater used for public supply affected by smaller underground release – MATTE **Category B** (impacts to groundwater used for public supply is classified as Category B as a minimum)

These are the unmitigated ratings and it was considered that a number of operational and maintenance factors could be added to reduce the frequency of the events by a factor of 10 (so in the 10^{-3} to 10^{-4} per year range). The two MATTE scenarios were plotted on the CDOIF tolerability matrix as shown in figure 7 after current mitigation measure had been allowed for.

	Frequency per establishment per receptor per year (**mitigated**)						
Annual frequency at which CDOIF Consequence Level is equalled or exceeded (mitigated)	10^{-8}–10^{-7}	10^{-7}–10^{-6}	10^{-6}–10^{-5}	10^{-5}–10^{-4}	10^{-4}–10^{-3}	10^{-3}–10^{-2}	>10^{-2}
D – MATTE			***TifALARP***			***Intolerable***	
C – MATTE					**•X1**		
B – MATTE	***Broadly Acceptable***				**•X2**		
A - MATTE							
Sub MATTE	Tolerability not considered by CDOIF						

Key: point X1 is a large release on the surface affecting surface water and point X2 is a smaller gradual release underground affecting groundwater

Figure 7. Example of Pipeline Z CDOIF Tolerability Grid (adapted from CDOIF, 2016)

The point marked X1 on the CDOIF grid for a large above ground leak indicates that a mitigated leakage frequency for a Category C MATTE is in the 10^{-3} to 10^{-4} per year range (1 in 1,000 to 1 in 10,000 years). This lies in the intolerable region and the risk must be reduced further if operation is to continue. The point marked X2 on the CDOIF grid represents a risk to groundwater from a gradual underground leak, which may not be picked up by leak monitoring system and may take some time to discover through inventory mass balances. It is judged that this would equate to a Category B MATTE (severe, long term harm) by following the CDOIF guidance which is reasonably prescriptive. The frequency of such a scenario is estimated to be of the same magnitude as for X1. This leads to a TifALARP risk from the X2 scenario. Hence, scenario X1 is the most severe scenario in terms of CDOIF risk level.

It is thus concluded that enhanced mitigation measures are required, almost irrespective of the costs involved, in order to reduce the CDOIF risk level for Pipeline Z. These measures may include:

1. Immediate repair of corroded sections
2. Replacement of protective coating on damaged sections
3. More regular pipeline inspection intervals
4. Reduced operating pressure
5. Re-training of process operators on pumping protocol and emergency procedures
6. Upgrade of leak detection and automatic pumping shutdown systems
7. Longer-term plan to replace the pipeline

Thus, in this example of an oil transfer pipeline, the regular annual inspections had not identified the level of risk posed. The CDOIF approach was found to be useful to identify the potential MATTE scenarios and the need for additional mitigation.

5. Refinery Tank Farm Case Study

WSP has gained experience of assessing MATTE risks associated with bulk storage areas at a range of refinery and terminal facilities. Bulk storage areas often contribute a significant proportion of the establishment risk due to the available source inventories (which have the potential to create high severity MATTE scenarios) and the large number of source points (typically 10's tanks for a terminal and possibly 100s in the case of a refinery).

Tank Farm Example

In this example, a large hydrocarbon product tank farm at a refinery was assessed using CDOIF guidance, and the key steps were:

- Review of tank locations, inventories and secondary containment, drainage and interceptor arrangements. Operating and maintenance procedures were examined to help identify potential for loss of containment.
- Identification and evaluation of source – pathway – receptor linkages for different credible accident scenarios. This includes demonstrating an understanding of the hazards of the establishment, and the sensitivities of the environment.
- Identification of tolerability criteria for relevant receptors, dependent on the receptor type and potential level of consequence to the receptor.
- Evaluation of risks to the receptor, through examination of accident scenarios (their consequences and frequency) and comparing this to the tolerability criteria derived above.
- Following completion of the risk assessment, determine what (if any) additional measures are required to demonstrate that the risk has been reduced to ALARP

As a starting point published generic failure rates such as those collated by the HSE (2001) should be used however for certain scenarios operators may have derived site-specific failure rates that can be applied.

For oil terminals and refineries the types of product is a key controller on the duration of a potential MATTE event and the resulting MATTE category. The Energy Institute (2017) guidance provides an approach for assessing MATTE duration to different types of chemicals. For example, similar hydrocarbon substances can be grouped (in terms of their PBT properties) and gasoline spills can be ruled out in early phases of the assessment under the Energy Institute approach.

When analysing establishment risks for terminal and refinery facilities, site specific factors to consider include:

- Construction and configurations of tank bunds
- Topography and drainage arrangements
- Presence and nature of tertiary containment

Traditionally considered failure mechanisms such as overfilling, chronic leakage from tank floors as well as catastrophic integrity loss should be considered alongside other initiating events that may cause a Major Accident Scenario to develop such as flooding or failures elsewhere within the establishment.

The size of terminal and refining installations dictates that the potential receptors form tank failure may vary with locations of the source across the site, underlining the importance of identifying credible S-P-R combinations early in the assessment.

Once the establishment risk attributable to tank failures has been evaluated, ALARP demonstration should focus on whether the risk associated with tank storage is evenly distributed across the site, requiring a site wide mitigation approach or driven by a relatively small number of tanks situated in sensitive locations. In the latter case targeted mitigation measures in discrete areas of the site can offer the greatest risk reduction. Physical mitigation measures such as interceptor pits and secondary containment may break the S-P-R linkage or reduce the volume of a release. Operational mitigation measures such as alarm systems, maintenance and operating procedures can reduce the volume and frequency of a release but are often subject to human error.

When assessing potential MATTE scenarios from bulk storage areas of refineries, the process starts with sound conceptualisation of the site and study area. A review of sources (tanks and their contents) will allow certain tanks to be screened out of further assessment, for example those storing gasoline and other volatile products, in line with the Energy Institute (2017) guidance.

Multiple tank failure mechanisms could result in a MATTE scale impact, these include high consequence low probability events (catastrophic failure) and (relatively) higher probability events such as chronic tank floor leakage. Overfilling is another typical failure mechanism considered in tank farm MATTE assessments. As a starting point published generic failure rates such as those collated by the HSE (2001) can be used however for certain scenarios operators may have derived site-specific failure rates that can be applied as part of their risk management. When using generic failure rates, it is important to understand the assumptions and limitations that sit behind the published values.

ITEM FAILURE RATES

Type of Release	Failure Rate (per vessel yr)
Catastrophic	5×10^{-6}
Major	1×10^{-4}
Minor	2.5×10^{-3}
Roof	2×10^{-3}

RELEASE SIZES

	Hole diameters for Tank volumes (m^3)		
Category	>12000	12000 – 4000	4000 - 450
Major	1000 mm	750 mm	500 mm
Minor	300 mm	225 mm	150 mm

Figure 8: Failure Rates and Release Sizes for Large (>450m³) Atmospheric Tank Storage (based on HSE, 2001)

In addition, external initiating events should be considered, where relevant, such as releases in process or loading areas of an establishment, flooding of the site or initiating events from identified neighbouring (domino) sites.

Assessment of the available pathways in the event of tank failure allows identification of the key receptors in tank failure scenarios. The pathways will often be dictated by the failure mechanism in an individual scenario, large release rate scenarios are more likely to be dominated by surface flows with the greatest potential impacts to proximal environments and those areas receiving drainage system effluent. In contrast, longer term releases such as chronic tank floor leaks have a higher potential of resulting in subsurface impacts to soil and groundwater. This conceptualisation will allow those parts of the study area to be identified that are most likely to be impacted through MATTE scenarios involving tank farm releases.

Once a representative set of potential MATTE scenarios have been developed a severity category is assigned to each potential MATTE scenario using the thresholds provided in the CDOIF guideline. Figure 9 is an example of the thresholds that would be applied where the scenario results in impact to a site of special scientific interest (SSSI).

Row	DETR Table Ref	Receptor Type	Severity of Harm				Reference to Table 2	Comments
			Significant *While this level of harm might be significant pollution, it is not considered a MATTE.*	**Severe** *DETR Criteria - the lowest level of harm that might be considered MATTE.*	**Major**	**Catastrophic**	*Corresponding Harm/Duration / Recovery row in Table 2*	*The 'Severe' to 'Catastrophic' levels of harm are considered to be included as 'Serious' with respect to the COMAH definition of a major accident.* *Receptors include:*
		Severity Level →	**1**	**2**	**3**	**4**		
1	1	Designated Land/Water Sites (Nationally important)	<0.5ha or <10%	>0.5ha or 10-50% of site area, associated linear feature or population	>50% of site area, associated linear feature or population	N/A	Land or Surface Water	NNR, SSSI, MNR

Figure 9: Example Severity Categories for a Scenario Impacting a SSSI (CDOIF, 2016)

For each scenario a duration category should also be assigned. The CDOIF guideline provided broad (non-chemical specific) categories as shown in Figure 10. Subsequent guidance provided by the Energy Institute (2017) to support the CDOIF approach has provided a more detailed process for analysing impact duration to land and surface water (but not groundwater) receptors, based on the type of chemical released and the nature of the receiving environment. It should be noted when assigning duration that the time period in question is the time taken for the receptor to naturally recover to its pre-impact status.

In the initial case severity and duration should be assigned for an unmitigated release (i.e. assuming all existing layers of protection that could influence the scenario post-release are ineffective). In this case the probability is largely a function of the initiating event frequency and the number of sources (tanks) available.

Description	Short term	Medium term	Long term	Very long term
	Harm with such short recovery is not considered a MATTE.			
Harm Duration Category →	1	2	3	4
Groundwater or surface water drinking water source (public or private)			Harm affecting drinking water source or SPZ < 6 years	Harm affecting drinking water source or SPZ >6 years
Groundwater (except drinking water sources): WFD Hazardous/Non Hazardous Substances	WFD hazardous substances < 3 months	WFD hazardous subs > 3 months	WFD hazardous subs > 6yrs	WFD hazardous subs >20 years
	WFD non-hazardous substances < 1yr	WFD non-hazardous substances > 1yr	WFD non-hazardous substances >10 years	WFD non-hazardous substances >20 Years
Surface water (except drinking water sources – see above)	< 1year	>1 year	>10 years	>20 years
Land	< 3 years or < 2 growing seasons for agricultural land	> 3 years or > 2 growing seasons for agricultural land	>20 years	>50 years
Built environment	Can be repaired in < 3 years, such that its designation can be reinstated	Can be repaired in > 3 years, such that its designation can be reinstated	Feature destroyed, cannot be rebuilt, all features except world heritage site	Feature destroyed, cannot be rebuilt, world heritage site

Figure 10: MATTE Duration Categories (reproduced from CDOIF, 2016)

Combining the severity and duration as per the matrix previously shown in Figure 4 provides the potential unmitigated MATTE consequence. The tolerability of the unmitigated impact should be assessed by comparing the calculated frequency to the tolerability threshold for the relevant MATE category, as illustrated example shown in Figure 11.

Factoring in the effect of existing mitigation measures such as secondary and tertiary containment may reduce potential MATTE consequence (through limiting the severity of the potential impact). The probability of failure on demand for mitigation measures should be evaluated using a site-specific approach as far as possible to account for specific features to the site such as tank and bund construction, bund configuration, site topography and drainage arrangements.

Annual frequency at which CDOIF Consequence Level is equalled or exceeded	10^{-8}–10^{-7}	10^{-7}–10^{-6}	10^{-6}–10^{-5}	10^{-5}–10^{-4}	10^{-4}–10^{-3}	10^{-3}–10^{-2}	$>10^{-2}$
D – MATTE			TifALARP			Intolerable	
C – MATTE						1	
B – MATTE	Broadly Acceptable				2		
A - MATTE							
Sub MATTE	Tolerability not considered by CDOIF						

Key: 1 = Unmitigated scenario impact, 2 = Mitigated scenario impact

Figure 11: MATTE Tolerability for Tank Farm Example (adapted from CDOIF, 2016)

To assess risks from the tank farm as a whole the probability of each MATTE consequence should be calculated for all the potential sources (tanks), to derive a probability per receptor per MATTE consequence level for tank farm scenarios. These figures can then be combined with contributions from any other potential sources that may impact that receptor. When considering risk at the establishment level, category C impacts to a given receptor, for example, are derived by summing the probability of all category C, B and A impacts to that receptor (but not category D impacts).

When approaching ALARP demonstration for tank farm areas, careful consideration should be given to the distribution of risk contribution across the bulk storage area. Due to their large footprint and the often highly variable distance between sources and receptors, the MATTE frequency can often be governed by a relatively small number of tanks. Identification of the key sources allows operators to maximise the potential effectiveness of any additional mitigation that may be justified by designing measures that provide the greatest risk reduction rather than considering less inefficient and often more expensive site wide solutions.

6. Conclusions

The relatively new CDOIF guidance on the assessment of environmental risk tolerability for COMAH sites provides a robust framework to demonstrate that ALARP measure are in place to minimise the risk of MATTE events. It relies upon screening of MATTE events to identify those that are significant, along with estimation of the frequency of such events. Standard methods to assess failure rates are employed such as comparison with industry benchmarks and QRA and may also rely on expert judgement and equipment inspection reports. Conceptualisation of the site study area, proximity to environmental receptors and pathways is key to accurately identify potential MATTE scenarios. Scenarios that are likely to drive establishment risk should be identified early so that the appropriate level of assessment detail can be applied to these potential MATTE events.

The overall environmental risk arising from all operations at the COMAH installation should be assessed. This will include all relevant MATTE events and all environmental receptors that could be significantly impacted, some of which may be up to 10 km distance from the site boundary. Since the guidance is relatively new, CDOIF assessments may be required by the CA as part of a wider site COMAH report update, or may be required as an improvement condition following a site incident or CA inspection.

For pipelines, traditional inspection reports do not fully assess the risks to the environment of a potential failure. It is reasonable to apply the CDOIF risk assessment methodology to transfer pipelines which extend beyond a COMAH site boundary and indeed the Competent Authority may expect this approach to be applied in future. For tank storage farms, tanks can be grouped and prioritised for more detailed assessment following the initial screening using the CDOIF approach. Where multiple scenarios have potential to impact the same receptor, the frequency of the MATTE outcome from these scenarios is aggregated. If the aggregated risk lies in the tolerable if ALARP region, then cost-benefit assessment can be used to demonstrate the suitability of mitigation measures.

Risk assessment using CDOIF provides an opportunity for operators to demonstrate the safety measures that they have in place. When completing ALARP demonstrations, operators and risk assessors should collaborate as early as possible in the process with the Competent Authority to gain alignment on approach and assessment parameters.

7. References

Chemical and Downstream Oil Industries Forum (CDOIF, 2016), Guideline, Environmental Risk Tolerability for COMAH Establishments v2.0.

COMAH Regulations 2015 (SI 2015 No. 209)

Department for the Environment, Transport and the Regions (DETR 1999). Guidance on the interpretation of Major Accident to the Environment for the purposes of COMAH regulations

Energy Institute (EI, 2017), Guide to predicting environmental recovery durations from major accidents. Supporting guide to the Environmental risk tolerability for COMAH establishments guideline

Health and Safety Executive (HSE, 1996), L82 Guide to Pipeline Safety Regulations 1996

Health and Safety Executive & Environment Agency (HSE & EA, 2010). Environmental Aspects of Safety Report Assessment, Section 13 Safety Report Assessment Manual.

Health and Safety Executive (HSE, 2001). Failure Rate and Event Data for use within Risk Assessments.

Health and Safety Executive and Environment Agency (HSE & EA, 2016). All Measures Necessary Guidance for COMAH.

International Association of Oil & Gas Producers (OGP, 2014), Riser & Pipeline Release Frequencies

Pipeline Safety Regulations 1996 (SI 1996 No. 825)

United Kingdom Onshore Pipeline Operators' Association (UKOPA, 2014), Good Practice Guide on Pipeline Safety Monitoring

United Kingdom Onshore Pipeline Operators' Association (UKOPA, 2015), Pipeline Product Loss Incidents and Faults Report 1962-2014

US Department of Transport (US DOT, 2010), Office of Pipeline Safety, Building Safe Communities: Pipeline Risk

US Pipeline Safety Trust (US PST, 2015), Independent Review of US Pipeline Risk Data