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Kingsgrove to Revesby Quadruplication and Turnback

Ethane Gas Pipeline Risk Assessment

Transport Infrastructure Development Corporation

MARSH

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Executive Summary

Marsh was contracted by Transport Infrastructure Development Corporation (TIDC) to carry out an assessment of risks due to a potential ethane pipeline incident associated with the Kingsgrove to Revesby and Turnback development projects. The primary objectives of the project were to:

1. Identify enabling events (root causes) related to the unwanted occurrence of an *ignition of ethane release from the pipeline due to the K2RQ or Revesby Turnback Project*
2. Document the control strategies which are in place to reduce the likelihood of the event occurring
3. Assess the relative probabilities for each initiating event
4. Evaluate the overall likelihood of a release
5. Determine the potential consequences of a release
6. Identify potential opportunities for further consideration as part of the overall project risk management plan
7. Quantitatively estimate the individual risk exposure to a person within the neighbouring community associated with the potential release of gas from the pipeline.

The method followed in this risk assessment involved five key stages, as discussed below.

Stage 1: Consequence Analysis

A detailed quantitative analysis was conducted to determine the potential consequences of a release of ethane. The risk analysis incorporated comprehensive computer modelling and aimed to determine the potential effect on a person within the neighbouring community as a result of such an incident.

Stage 2: Fault Tree Development

The Fault Tree model for the *Ignition of an ethane release due to the K2RQ or Revesby Turnback Project* was developed during a workshop with TIDC representatives together with other stakeholders in the construction project.

The loss scenario was considered as the starting point following previous discussions between TIDC and Marsh.

This workshop determined and documented the root causes of the loss scenario and where necessary, identified and documented current mitigating controls. A level of detail sufficient for the purposes of quantification was developed using the fault tree logic described in Appendix C.

Stage 3: Fault Tree Verification & Quantification

The fault tree was quantified by estimating a probability for each fault mode. The adequacy and reliability of controls in these areas were considered in ascertaining these probabilities.

Initial quantification of the input modes for the fault tree was carried out in the workshop using the experience of project stakeholders, incidents that have occurred within the industry and Marsh's risk management expertise.

The initial fault tree structure was refined following the first workshop from stakeholder feedback. This process provided an opportunity to review the logic, and question the assumptions made.

Stage 4: Sensitivity Analysis

It is recognised that best estimates are used in the quantification of the fault tree. That is there is uncertainty for each input. This uncertainty can be incorporated into the mathematical model by providing credible variance for each input and ultimately deriving a distribution for each input. Stochastic modelling can be used to statistically combine these uncertainties to provide a distribution and subsequent confidence level of the output. Refer to Appendix D for more details on the Stochastic modelling.

Stage 5: Analysis of individual risk

Based on the frequency (Fault Tree) and consequence analyses described above, the level of individual risk associated with the Proposal was evaluated. This evaluation considered both the existing (or background) risk level, as established at the time of the pipeline's construction, and the effect that the Proposal will have on this risk level. The estimated individual risk level was then compared with established risk acceptance criteria, to determine whether a tolerable risk level will be achieved.

The consequence analysis considered some 720 release scenarios, and determined that the worst case event would have a potential interaction length of 690m. The scenario in question is based upon all influencing factors being at their most adverse, allowing a major ethane release to form a vapour cloud, which is subsequently ignited.

The Fault Tree analysis indicated the probability of an ethane release due to the TIDC project to be a 1 in 250,000 year event. Monte Carlo simulations (a statistical modelling technique – See also Appendix D) tested the reliability of the analysis. Under simulation,

a 95% confidence interval shows that the return period lies between 1 in 137,000 years and 1 in 475,000 years.

Using the data from the consequence and Fault Tree analyses, it has been estimated that the maximum individual risk associated with releases of ethane due to the project is less than 0.37 in one million years (see Section 7). When combined with a recalibrated background risk level, as established prior to the pipeline's construction, the total maximum individual risk during the project is estimated as 0.87 in one million years. This figure is below the established risk tolerance criterion (residential) of one in one million years and it is therefore concluded that the project does not result in an unacceptable level of individual risk.

Whilst this result demonstrates the very low likelihood of a pipeline ignition, our analysis identifies which factors have the greatest influence on the result and their associated controls. The relative importance of these specific root causes is important as it identifies the areas where controls are most critical.

This report includes a section on opportunities for consideration in managing those specific risks. Any further actions can be included within the Fault Mode and Control Table that has been developed. This is an important tool for the ongoing management of all the root causes and their associated controls.

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Introduction

Background

The Kingsgrove to Revesby Quadruplication and Revesby Turnback Projects (the Project), will involve major construction works along an approximately 8.5km rail corridor between Kingsgrove and Revesby Stations.

The rail corridor is traversed by an existing ethane gas pipeline, connecting Quenos' Botany chemical complex with natural gas fields at Moomba. The pipeline carries high pressure ethane, a flammable gas, which introduces a potentially significant hazard in the event of a release and subsequent ignition.

Transport Infrastructure Development Corporation (TIDC) appreciates the hazard associated with the pipeline, and as such engaged Marsh to prepare this report examining the magnitude of the risk and the effectiveness of the proposed control strategy, which aims to maintain this risk at a tolerable level.

Scope

The scope of this assessment was:

1. Identification of enabling events (root causes) to the unwanted occurrence of an *ethane release from the pipeline due to the K2RQ or Revesby Turnback Project*
2. Documentation of the control strategies which are in place to reduce the likelihood of the event occurring
3. Assessment of the relative probabilities for each initiating event
4. Evaluation of the overall likelihood of the release
5. Determination of the potential consequences of a release
6. Identification of potential opportunities for further consideration as part of the overall project risk management plan
7. Quantitative estimation of the individual risk to a person within the neighbouring community associated with the potential release of gas from the pipeline.

Approach

The consequence analysis (item 5 above) was completed by Marsh, based on information provided by TIDC and from historical data. The initial analysis was reviewed in a workshop in December 2006, to ensure that the risk had been appropriately represented.

The causal and frequency analyses (items 1-4 and 6 above) were completed over two workshops at TIDC's onsite office in Revesby, Sydney on the 16th and 23rd March, 2007. The workshop formats ensured the most reliable information was collected and collated to promote a consensus of findings by all stakeholders. Marsh facilitated the workshops.

The estimation of individual risk was conducted on the basis of the consequence and frequency analyses, with consideration of previous quantified risk analyses, conducted prior to the construction of the pipeline.

The method followed in this risk assessment involved five key stages, as discussed below.

Stage 1: Consequence Analysis

A detailed quantitative analysis was conducted to determine the potential consequences of a release of ethane. The risk analysis incorporated comprehensive computer modelling and aimed to determine the potential effect on a person within the neighbouring community as a result of such an incident.

Stage 2: Fault Tree Development

The Fault Tree model for the *Ignition of an ethane release due to the K2RQ or Revesby Turnback Project* was developed during a workshop with TIDC representatives together with other stakeholders in the construction project.

The loss scenario was considered as the starting point following previous discussions between TIDC and Marsh.

This workshop determined and documented the root causes of the loss scenario and where necessary, identified and documented current mitigating controls. A level of detail sufficient for the purposes of quantification was developed using the fault tree logic described in Appendix C.

Stage 3: Fault Tree Verification & Quantification

The fault tree was quantified by estimating a probability for each fault mode. The adequacy and reliability of controls in these areas were considered in ascertaining these probabilities.

Initial quantification of the input modes for the fault tree was carried out in the workshop using the experience of project stakeholders, incidents that have occurred within the industry and Marsh's risk management expertise.

The initial fault tree structure was refined following the first workshop from stakeholder feedback. This process provided an opportunity to review the logic, and question the assumptions made.

Stage 4: Sensitivity Analysis

It is recognised that best estimates are used in the quantification of the fault tree. That is there is uncertainty for each input. This uncertainty can be incorporated into the mathematical model by providing credible variance for each input and ultimately deriving a distribution for each input. Stochastic modelling can be used to statistically combine these uncertainties to provide a distribution and subsequent confidence level of the output. Refer to Appendix D for more details on the Stochastic modelling.

Stage 5: Analysis of individual risk

Based on the frequency (Fault Tree) and consequence analyses described above, the level of individual risk associated with the Proposal was evaluated. This evaluation considered both the existing (or background) risk level, as established at the time of the pipeline's construction, and the effect that the Proposal will have on this risk level. The estimated individual risk level was then compared with established risk acceptance criteria, to determine whether a tolerable risk level will be achieved.

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Context of Risk Assessment

Risk Overview

The ethane gas pipeline, which runs through the railway easement in question has a nominal bore of 200mm and a wall thickness of 11.9mm. The pipeline operates at a maximum allowable pressure of 10,000kPa, at which ethane exists as a supercritical liquid, although actual operating pressure is typically around 7,100kPa.

Throughout the area of interest, the pipeline is continuous, with no identified valve stations. The total length of pipeline between valve stations is estimated at 10km. The valves are designed to close automatically in the event of pressure drop, limiting the inventory available for release in the event of a leak or rupture.

The pipeline is buried some 1.8m below grade.

The land uses adjacent to the pipeline corridor are predominantly residential and commercial properties. The closest occupied residential area to the pipeline is separated by approximately 20m.

No schools or medical facilities were identified within the lethality contours, as determined from the consequence analysis (Section 4).

Hazard Identification

The primary hazard, to which this report refers, is a potential release of ethane from the high pressure pipeline, which is subsequently ignited. This could potentially lead to a range of scenarios, including:

- Jet Flame/Fire Ball;
- Flash Fire; and
- Vapour Cloud Explosion

For immediate or early ignitions a jet flame will be the most likely result, whereas delayed ignitions will typically result in a flash fire or a vapour cloud explosion. Vapour

cloud explosions represent the most significant hazard, with the capacity to result in damage and injury well beyond the extent of the released plume. For this reason, and in the interests of conservatism, all delayed ignition scenarios were modelled as vapour cloud explosions.

Depending of the proximity of persons exposed to such events, the impacts may range from minor injury to, under adverse conditions, fatality.

The factors which contribute to this hazard were analysed in detail using the Fault Tree Analysis technique. This analysis is discussed in more detail in Section 5 of this report, however the key contributors to the risk are summarised below:

- Subsidence causing pipeline rupture
- Accelerated corrosion due to increased electrical currents causing pipe failure
- External fire causing pipe failure
- Deliberate attack on pipe during project
- Impact from authorised digging, drilling or piling causing pipe failure
- Impact from unauthorised digging, drilling or piling causing pipe failure
- Impact from dropped load causing pipe failure
- Excessive vibration causes pipe failure
- Train impacts pipe causing pipe failure

Each of these hazards is further investigated in the Fault Tree Analysis, which considers the combinations and permutations of circumstances which could lead to their eventuation and subsequent progression to an ethane ignition event. The risk control features, which serve to reduce the likelihood of each contributing factor, are also discussed within the Fault Tree Analysis.

4

Consequence Analysis

Consequence Modelling

The consequences of a wide range of release scenarios were analysed to determine the maximum foreseeable event, as well as the impacts of less significant, but more likely scenarios.

In total, some 720 release scenarios were modelled, taking into account variations in key influencing parameters, as tabulated below.

Table 4.1: Parameters influencing release scenarios

Influencing Parameter	Scenarios Considered
Orientation of release	Horizontal, angled
Atmospheric conditions	Atmospheric stability “D” and “F”
Time of Day	Day, Evening and Night
Wind speed	1.5m/s and 5m/s
Size of release aperture	20%, 50% and Full Bore
Time to ignition	No Ignition, Immediate, Typical Delay, Worst Case Delay
Wind direction	N, E, W and S

In all cases, the ambient temperature was set at 25^0C and the pipeline pressure was set at its maximum of 10,000kPa.

The relative probability of each of these conditions arising was estimated, based on historical data and information from the Met Bureau, in the case of weather conditions. This is discussed further in Section 8.

The release scenarios were modelled using the specialist software package, PHAST, which has been developed and extensively tested and validated by DNV.

In general terms there are three types of event that can result from the ignition of a release of ethane, namely:

- Jet Flame/Fire Ball;
- Flash Fire; and
- Vapour Cloud Explosion

For immediate or early ignitions a jet flame will be the most likely result, whereas delayed ignitions will typically result in a flash fire or a vapour cloud explosion. Vapour cloud explosions represent the most significant hazard, with the capacity to result in damage and injury well beyond the extent of the released plume. For this reason, and in the interests of conservatism, all delayed ignition scenarios were modelled as vapour cloud explosions. Immediate ignition scenarios were modelled as jet flames.

The overpressure effects of vapour cloud explosions were calculated in PHAST using the Baker-Strehlow method, conservatively assuming that 100% of the released plume is contained within a moderately confined region (ie, around built up structures). Based on NSW Department of Planing Guidelines, the fatality threshold for overpressures caused by vapour cloud explosions is considered to be the 21kPa contour, where a fatality rate of approximately 20% would be expected.

Flame effects for jet fires were assessed using the Shell method in PHAST. The fatality threshold is taken as 12.5kW, in accordance with NSW Department of Planning Guidelines.

Key Findings

The consequence analysis, as described above, was used to determine the effects of the worst case release scenario. With all of the release conditions (Table 4.1) at their most adverse, the worst case vapour cloud explosion could have an effect radius of 345m (690m diameter), based on the criteria above.

In terms of the immediate ignition, jet flame scenarios, the largest effect radius is 80m.

All other modelled scenarios were determined to have effect radii less than these values, for the respective type of incident. This means that for an individual located at any point on the pipeline, a release and subsequent ignition would have to occur within 345m either side of their location in order for a fatality to result. This total distance of 690m (ie, 2 x 345m) is referred to as the interaction length.

5

Fault Tree Construction

Development of the Fault Tree

The Risk Workshop held on Friday 16th March, 2007 commenced with the development of a Fault tree describing the root causes of an ethane pipeline release associated with the Kingsgrove to Revesby Quadruplication and Revesby Turnback development projects. This fault tree is included in Appendix A.

This 'logic' diagram illustrates the various incident pathways that may lead to an ethane pipeline release and includes combinations of circumstances necessary for an event to occur. A technical description of the construction and application of Fault Trees has been included in Appendix C.

Fault Tree quantification

In order to assess the impact of various controls on the risk of an ethane pipeline incident, it was necessary to quantify the Fault Tree in accordance with Fault Tree Analysis (FTA) theory. The rules and conventions of Fault tree quantification, as outlined by P.L.Clemens (2002) are included in Appendix C.

The risk of experiencing the ethane pipeline incident was quantified in the second workshop held on Friday 23rd March, 2007. Probabilities were assigned using expert opinion, historical data (where available), field data and FTA convention.

The table overleaf details the probability for each identified root cause and the means by which it was established.

NOTE - The occurrence of the top fault tree event does not imply a fatality as a foregone conclusion. The likelihood of a fatality (and/or injury) would be a function of other contributing factors (eg time of day). When making a direct comparison with acceptable individual risk levels (see Section 8 and Appendix E), the likelihood of the top event must be considered in conjunction with the associated likelihood of the release being ignited within the defined interaction length of the pipeline.

Table 5.1	Probabilities used in Fault Tree Analysis		
Cell	Root cause	Estimation	
		Likelihood	Estimated by
3.0	Ethane in the Pipe	1.0	It was assumed that Ethane is always present in the pipeline
3.2	Ethane escapes promoting cloud	1.0	It was assumed that a cloud will always be formed
3.3	Suitable wind and atmospheric conditions	1.0	It was assumed that a cloud will always form. The size of the cloud will depend on the wind & atmospheric conditions
4.1	Subsidence	1 x 10^-8	Calculation based on approximation of contributing factors, together with pre-existing infrastructure, design & controls
4.2	Accelerated corrosion due to electrical currents	c.0	Assumed to be almost zero based on effectiveness of controls
4.3	External fire (eg Vehicle, building, vegetation)	c.0	Assumed to be almost zero based on the location of the pipe
4.4	Attack on pipe during project	5 x 10^-7	Calculation based on assumed threat level
5.1	Enough force from impact to damage pipe	0.01	Approximation based on having enough force and being at a sufficient angle to impact pipe
6.2	Vibration	0.0001	Approximation based on existing controls
7.1	Heavy load crushing pipe	0.0001	Approximation based on control of vehicles, greater than 8 tonnes, being within the 2m hazard zone
8.1	Unauthorised digging impacts pipe with sufficient force/equipment, angle at location of pipeline	0.0001	Approximation based on site security, induction and co-ordinator meetings
8.4	Derailment due to defect in train system	0.01	Approximation considering industry data
8.5	Derailment travels in direction of pipe	0.50	Assumed that there is an equal probability of the train derailing either side of the track
8.6	Pipe sufficiently exposed	0.01	Conservative approximation based on the limited time that the pipe is exposed during the works
8.8	Derailment travels in direction of pipe	0.50	Assumed that there is an equal probability of the train derailing either side of the track
8.9	Pipe sufficiently exposed	0.01	Conservative approximation based on the limited time that the pipe is exposed during the works
9.1	Pipe in digging zone	0.0002	Calculation based on pinch point working area as a percentage of total area
9.5	Train dynamic appropriate to derail	0.50	Assumed that the train has a sufficient dynamic 50% of the time, that should a object be placed in its path, then it will derail
10.1	Wrong information (eg pipe location, wrong version of drawing used)	0.001	Historical human-error data
10.2	Information interpreted incorrectly	0.001	Historical human-error data
10.3	Measuring equipment error	0.001	Assessment based on workshop feedback
10.4	Operator unfit to undertake work causes error	0.001	Approximation based on industry experience and controls

Table 5.1	Probabilities used in Fault Tree Analysis		
Cell	Root cause	Estimation	
		Likelihood	Estimated by
10.5	Train traveling on track	0.05	Conservative estimate of train travelling on the track
10.6	Work disturbs track	0.01	Conservative estimate
10.7	Disturbances on track not fixed	0.01	Conservative estimate
11.0	Flaw leads to digging in wrong spot	0.001	Assessment based on historical human-error data
11.1	Failure to detect/ remedy flaw	0.001	Assessment based on historical human-error data

6

Current and Potential Controls

Control Table

Current and potential controls have been documented in the Fault Mode & Control Table included in Appendix B.

It is intended that this table will provide the tool for the ongoing management of risks, which could contribute to a pipeline incident.

Risk Management plan

For the control table to be effective, it needs to be converted into management plans that are consistent with TIDC's risk management approach for the project. For example, this will provide each responsible person, accountable person and auditor with their list of "jobs". Also, the control tables can be incorporated within the site's current risk management software. It can be used to analyse man power planning, training needs, and then timetable actions.

As part of this report, the analysis identifies the relative importance of contributing factors. The analysis specifically identifies those factors which have the greatest influence on the final result. This report identifies issues that TIDC could consider in managing these risks, in addition to existing controls, and thus reducing the likelihood of their occurrence.

7

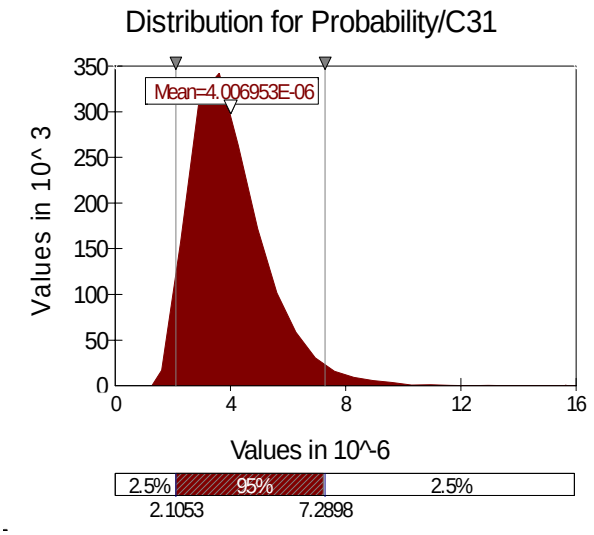
Fault Tree Results and Analysis

Model results

The mean probability for the loss scenario as derived from 10,000 Monte Carlo simulations is 4.007 x 10^{-6}. This equates to a return period of approximately 1 in 250,000 years. The expected value without simulations is 1 in 248,872 years, the closeness of these results gives confidence that the calculations within the model are correct and that the assumptions used are appropriate for this scenario.

The probability distribution produced from 10,000 iterations of the Monte Carlo simulation is shown in Figure 7.1.1 below and a summary table of results is shown in Figure 7.1.2 over.

Figure 7.1.1: Pipeline incident – Probability Distribution Curve



Statistic	Probability	Return Period
Minimum	1.27×10^{-6}	1 in 785,000 yrs
Maximum	1.60×10^{-6}	1 in 62,000 yrs
Mean	4.007×10^{-6}	1 in 250,000 yrs
Median	3.76×10^{-6}	1 in 266,000 yrs
2.5 percentile	2.11×10^{-6}	1 in 475,000yrs
97.5 percentile	7.29×10^{-6}	1 in 137,000 yrs

Figure 7.1.2: Pipeline incident – Summary Table

The results presented in Figure 7.1.2 above show that the mean return period is approximately 1 in 250,000 years with a 95% confidence interval that the return period lies between 1 in 137,000 years and 1 in 475,000 years. The maximum return period generated from the 10,000 iterations was 1 in 63,000 years.

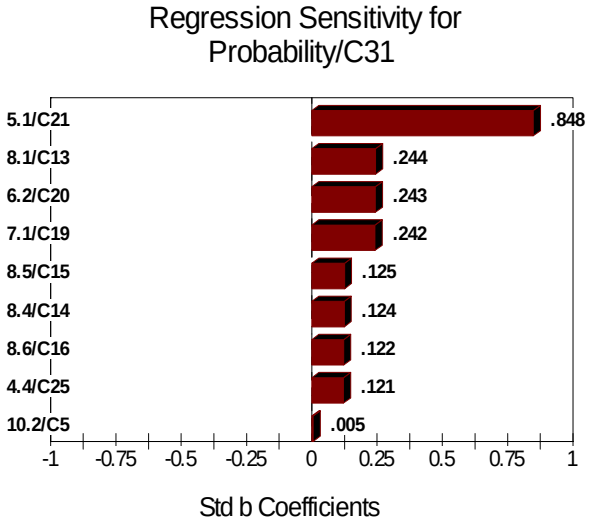


Figure 7.1.3: Pipeline incident – Regression Sensitivity Tornado Graph

Figure 7.1.3 above demonstrates stepwise regression of the Fault Tree input uncertainties. Box numbers corresponding to the fault tree are shown on the y-axis and regression coefficients on the x-axis. This graph shows that the most sensitive input variable in the model is box 5.1, that is, “Enough force from impact to damage pipe”.

Sensitivity analysis of this specific fault within the model shows that by changing the input probability of this fault mode 5.1, the overall result mean changes as follows:

	Probability of #5.1	Overall Result Mean	Return Period
Scenario 1	0.10	3.55×10^{-5}	1 in 28,000 yrs
Existing input probability	0.01	4.01×10^{-6}	1 in 250,000 yrs
Scenario 2	0.001	8.59×10^{-7}	1 in 1,165,000 yrs

This demonstrates the level of impact this fault mode has on the overall result and demonstrates that the level of significance this factor has on the overall result. Reducing the likelihood of this event significantly reduces the likelihood of the overall top event.

On analysis, the next most sensitive factors are:

- 8.1 - Unauthorised digging impacts pipe with sufficient force/equipment, angle at location of pipe
- 6.2 - Vibration, and
- 7.1 - Heavy load crushing pipe.

Section 9 identifies opportunities for consideration in managing these specific risks. The opportunities can be used as a checklist with the project's existing risks management initiatives.

Comparative analysis - verification of fault tree analysis

Data collected by EGIG (European Gas pipeline Incident data Group) shows that the 5 year moving average overall failure frequency, which represents the average incident frequency over the period (2000 – 2004), equals 0.17 per year per 1,000 km:

- This report's model produces a probability of 4.01×10^{-6} for "Ignition of an ethane release due to the K2RQ or turnback project"
- Whilst this result may provide comfort to TIDC, historic causation data (see Appendix F) for pipeline failure highlights the need for the continual review of existing controls for all contributing factors with particular attention to those root causes associated with "outside force"
- Moreover, sensitivity analysis of our model has identified the factors that have most influence on the overall result. This will allow for the prioritisation of any further mitigation strategies and initiatives as required.

Furthermore, the data also shows that the location of the pipe (ie burial depth) provides no significant amount of protection against outside force incidents:

- Our analysis in conjunction with this data confirms the factors identified in the sensitivity analysis, and the impact that “outside force” has on pipeline failure rates
- Furthermore, this data confirms discussions during the workshops where it was stated that “unauthorised digging”, specifically by outside parties, was “a very significant risk” to the project
- The data reaffirms the need for ensuring effective controls in minimising the impact from vibration and excessive loads on site – both identified as significantly influencing factors
- Existing controls were identified in the workshop to manage these specific root causes. These can be reviewed in conjunction with the list of **opportunities for consideration** included in the following section. This can be used as a checklist in conjunction with the project’s overall risk management strategy.

8

Assessment of Individual Risk

Definition

Individual risk is defined as the likelihood of a specified level of harm at a specified location. The risk levels discussed below are measures of individual fatality risk.

The NSW Department of Planning Guidelines have established an individual fatality risk land use planning criteria of less than one in one million per year for residential areas. The maximum individual fatality risk associated with the project should therefore be below one in one million per year.

Background Risk

The background (existing) level of individual risk associated with the normal operation of the pipeline was calculated by ICI, prior to its construction. A tolerable risk of one in one million per year was determined in accordance NSW Department of Planning Guidelines.

This value equates to the maximum individual risk exposure to any individual within the neighbouring community, associated with the normal operation of the pipeline. It is an average value of the life of the pipeline, which does not specifically include risks associated with the proposed project.

Effect of Project on Background Risk

Although the background risk does not specifically include risks associated with the proposed project, it does include an allowance for incidents associated with external interference on the pipeline. The background risk analysis suggests that approximately 23% of pipeline releases are due to external interference, however, because such events are more likely to cause relatively large releases and therefore ignitions, the proportion of ignition incidents associated with external interference is estimated at 53%. Furthermore, it can be concluded that the proportion of the individual fatality risk associated with external interference is at least 53% or 0.53 in a million years.

These percentage contributions have been determined using the raw data and the event tree methodology presented in the background risk report, prepared by ICI, prior to construction of the pipeline.

The likelihood of a release from the pipeline (Fault Tree Analysis), due to the project, was calculated as four in one million years, however this is not an individual risk value. The pipeline release probability represents the likelihood of a release over the full 7.5km of the project however, as determined in Section 3, for an individual to be lethally effected by a release it must occur within 345m either side of them, or within a total interaction length of 690m (ie, 2 x 345m). It is therefore necessary to calculate the maximum probability of a release from any single 690m section of the pipeline.

In order to achieve this, a risk profile of project-pipeline interactions, prepared by the principal construction contractor was analysed. This risk profile, presented in Appendix G, qualitatively categorises sections of the pipeline as *high, medium* or *low* risk, depending on its proximity to project works. Assuming that *high* risk sections are five times more likely to be the source of a release that *medium* risk sections, and that *low* risk sections have a very low release likelihood, the probability of a release emanating from a *high* risk region has been estimated at 88% of the total release likelihood, or 3.52 in a million years. The value of 88% is derived from the relative total lengths of *high* and *medium* risk sections of the pipeline, weighted against the relative release likelihoods for each risk category.

The probability of release occurring in any single 690m section of a *high* risk pipeline represents the maximum probability of release occurring, which could impact an individual at a fixed point on the pipeline. A length of 690m represents 21% of the total *high* risk length resulting in a maximum likelihood of release in single interaction length of 0.74 in a million years.

In order for a release of ethane to result in a fatality it must first be ignited. The weighted average probability of ignition across all release scenarios is estimated at 50%. This means that the probability of an ignited release of ethane occurring, in the highest risk interaction length, due to the project, is approximately 0.37 in a million years.

Not all such incidents will necessarily result in a fatality, so the individual fatality risk must be less than 0.37 in a million years. This assertion is supported by the following summary of conservative assumptions which have been incorporated into the analysis, ie:

- The use of a single 690m interaction length basically assumes that all of the potential release scenarios have the same interaction length as the worst case scenario, or in other words, that the worst case result is inevitable given a release. In fact, the worst case scenario represents a very small fraction of the possible outcomes, all of which have shorter interaction lengths, thus contribution less to the overall likelihood.

- Individual risk has been calculated at a location on the pipeline. In fact, potentially impacted individuals are separated by approximately 20m and therefore less likely to be effected.
- The calculated individual risk is only applicable over a continuous 690m section of *high* risk pipeline. There are very few continuous *high* risk sections, and therefore, in most areas, the overall likelihood is lower.
- The weighted average of probability of ignition given a release has been set at 50% for this study. In fact, some data suggests that the true value is significantly lower, in the vicinity of 25%. A value of 50% is therefore considered conservative.

Because a tolerable individual risk level can be demonstrated on the basis of these assumptions, it is not necessary to continue the frequency analysis and further reduce the calculated number via more complex calculations.

Conclusions

Because of the heightened access controls and activity during the project, the probability of external interference, other than project-related activities themselves, is reduced close to zero. This means that we would overstate the individual risk during the project by simply adding the project-related individual risk to the background risk of one in a million years. In fact, when the external interference component of the background risk is removed, and the project-related risk added to the result, the total individual risk exposure during the project reduces to less than 0.84 ($1x10^{-6}$ – greater than $0.53x10^{-6}$ + less than $0.37x10^{-6}$) in a million years.

The individual risk level is therefore within the planning criteria of one in a million years. It is also less than the background risk, which may be explained by the heightened level of access control and safe working procedures under which the project is to be conducted.

The analysis provided here is well aligned with historic pipeline failure causation data (see Appendix F) from the US over a 15 year period, which shows that 54% of reportable pipeline incidents were caused by “outside force” and that 67% of these “outside force” incidents were caused by “equipment used by outside parties”. This suggests that by more effectively controlling outside parties, as will be achieved during the project, the overall risk can actually be reduced in comparison to the background risk.

9

Opportunities for Improvement

Project Risk Management involves conducting risk management planning, engaging in risk identification, completing risk analysis, creating a risk response action plan, and monitoring and controlling risk on the project. Project Risk Management is a continuous process to be engaged in through out the entire project. Whilst this section concentrates on four specific root causes, all risks should be continually reviewed throughout the entire project.

Through sensitivity analysis, we have identified those contributing factors that have the most influence on the overall model result. Potential opportunities for improvement in these four areas are included in the following tables:

Fault Table Ref	#5.1
Root cause	**Enough force from impact to damage pipe**
Existing controls	Initial design & construction of pipeline protection (eg concrete cover etc)
Potential opportunities	▪ Investigate integrity of pipeline and surrounding concrete protection prior to any digging ▪ Undertake specific risk assessment for any digging/piling activity based on the area of excavation, equipment being used, ground condition, weather etc ▪ Produce Safe Work Method Statement (SWMS) and conduct briefing session before commencing work ▪ Ensure monitoring of excavation, including post-activity ground review (ie to ensure no pipeline damage and/or gas leak) ▪ Provide feedback to project management in order to update any future SWMS

Fault Table Ref	#8.1
Root cause	**Unauthorised digging impacts pipe with sufficient force/equipment, angle at location of pipe**
Existing controls	Interface co-ordination meetings
Potential opportunities	▪ Undertake risk assessment of site security to identify potential unauthorised digging or related activities ▪ Liaise with third parties (eg rail network) to identify future works, access control and timelines during critical work ▪ Consolidate work areas to well defined locations that can be secured ▪ Implement/review "dial before you dig" call line ▪ Implement/review signage along pipeline with procedure details and emergency numbers ▪ Implement/review contractor risk management program ▪ Implement work orders for any third party work being started. This should include a risk assessment as well as site briefing. Work to be reviewed to ensure pipeline and rail integrity ▪ Routinely patrol pipeline to identify any unauthorised activities

Fault Table Ref	#6.2
Root cause	**Vibration**
Existing controls	*Controls from contributing factors:* ▪ Vibration minimisation (7.4) ▪ Geotechnical risk assessment (7.5)
Potential opportunities	▪ Implement vibration monitoring program and impose a maximum ground movement / acceleration coefficient limit ▪ Identify equipment with excessive vibratory effects and potential impact on pipeline integrity ▪ Ensure sufficient monitoring and review of any activity that creates excessive vibration ▪ Identify vibration control measures (ie re-balancing of equipment) ▪ Identify areas of potential ground movement/subsidence and review controls ▪ Increase excavation distances where possible to reduce vibration effects

Fault Table Ref	#7.1
Root cause	**Heavy load crushing pipe**
Existing controls	*Controls from contributing factors:* ▪ Use experienced site foreman to supervise works (8.2) ▪ Safe Work Methods Statements (8.3) ▪ Guarding of pipe with concrete protection slabs (8.3)
Potential opportunities	▪ Determine and review the maximum load permissible in and around the site ▪ Undertake pigging to determine exact depth of pipe in areas where excessive loads are in operation ▪ Implement barricading around areas where pipe is exposed or where pipe depth is less than the minimum depth for load ▪ Implement signage around areas with known voids or potential subsidence ▪ Implement restricted access to site for excessive loads ▪ Marshalling of excessive loads on site ▪ Identify area for storing of excessive loads ▪ Review area of excessive load post work to determine if any damage has occurred

Appendix A

Fault Tree

See overleaf

TIDC - Pipeline Incident

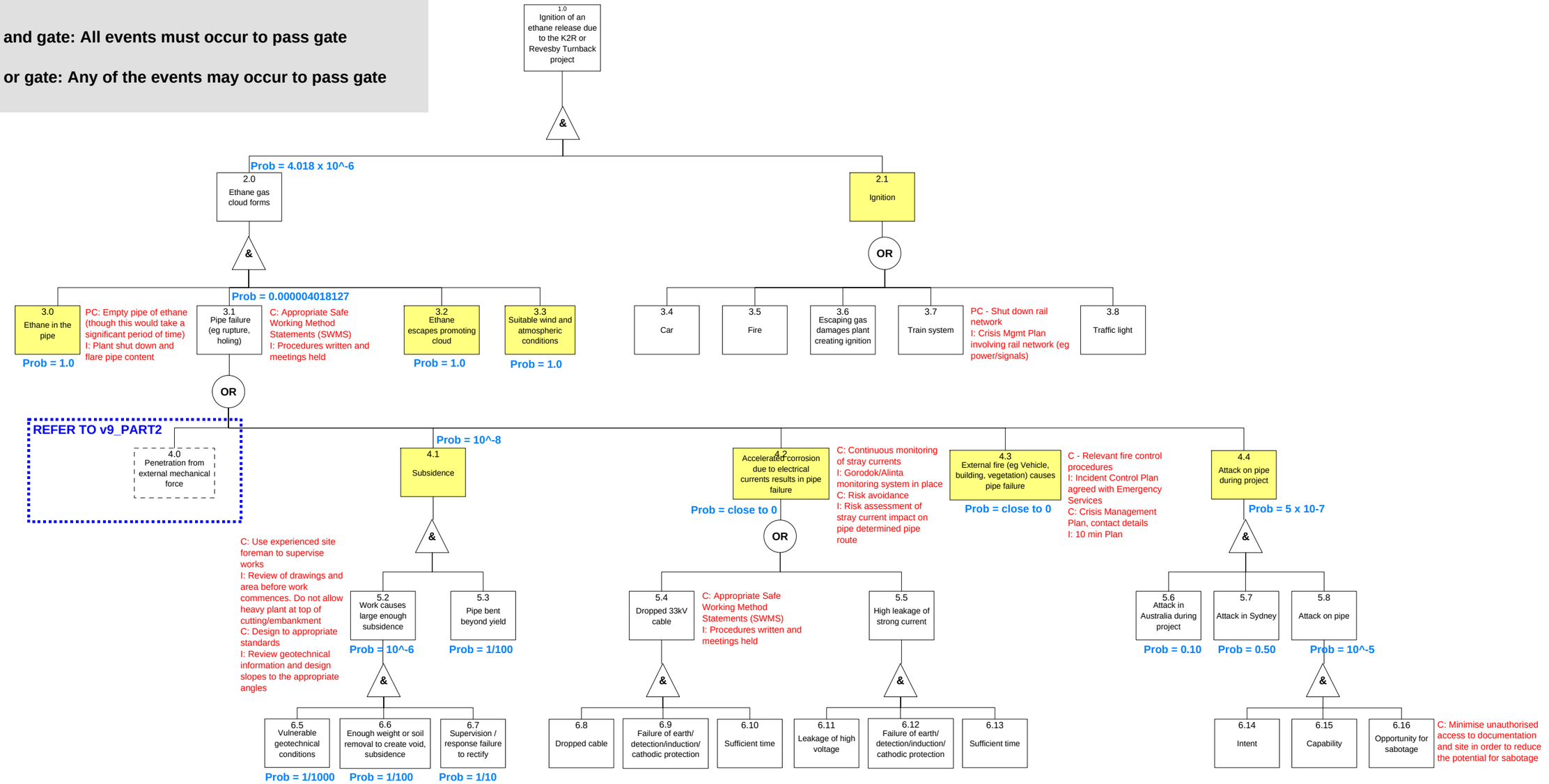
Fault Tree Analysis

Version Number: 9.0 - Part 1

Drafted by: Rob Gardiner

& - and gate: All events must occur to pass gate

OR - or gate: Any of the events may occur to pass gate



TIDC - Pipeline Incident

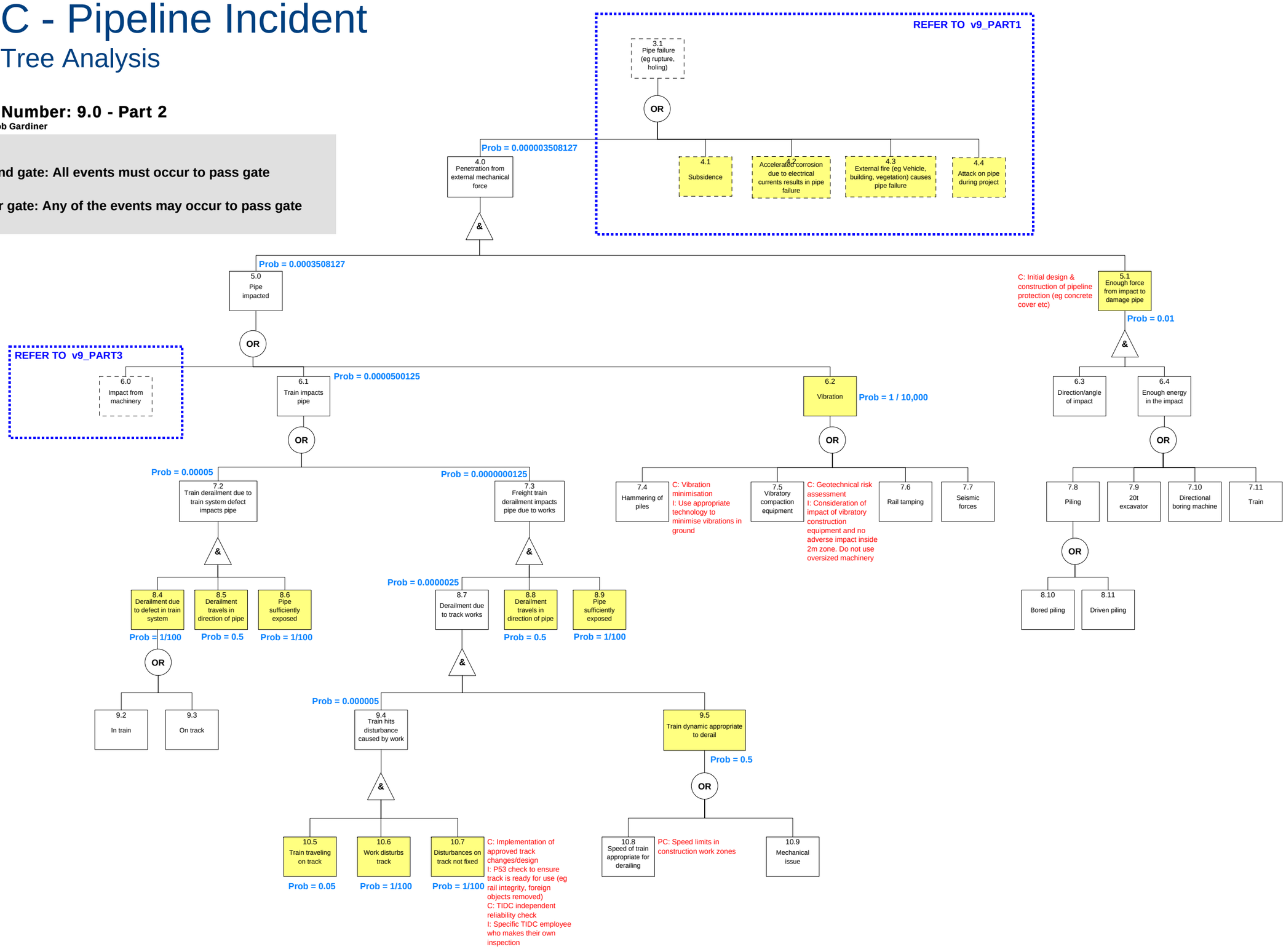
Fault Tree Analysis

Version Number: 9.0 - Part 2

Drafted by: Rob Gardiner

& - **and gate: All events must occur to pass gate**

OR - **or gate: Any of the events may occur to pass gate**



TIDC - Pipeline Incident

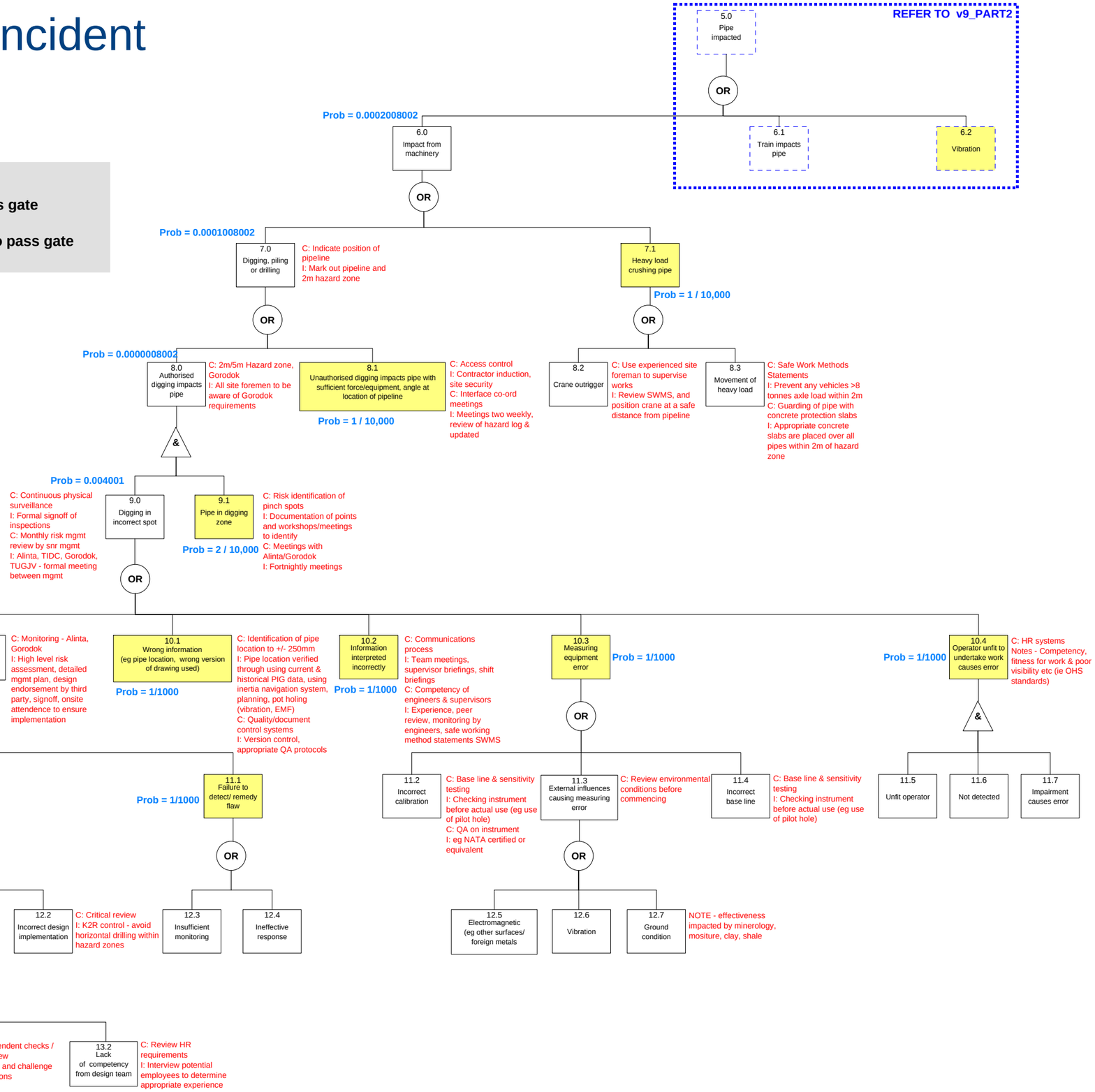
Fault Tree Analysis

Version Number: 9.0 - Part 3

Drafted by: Rob Gardiner

& **- and gate: All events must occur to pass gate**

OR **- or gate: Any of the events may occur to pass gate**



Appendix B

Fault Mode and Control Table

The Fault Mode and Control Table heading definitions are listed below:

Fault Tree Reference Headings

- Ref: Reference, the file path in the Fault Tree to the fault node
- Fault Mode: What can go wrong (may be a root cause)
- Nature of Control: The Control concept, methodology, process, etc

Roles of responsibility and accountability should be reviewed for the effective implementation of all existing controls identified in the workshop.

Existing Controls

- Implementation Method: A description or reference as to how the control is carried out
- Responsibility: The person assigned responsibility for undertaking the implementation of the control
- Accountability: The person assigned accountability for ensuring the control is implemented. They may not actually do "it", but are accountable if "it" does not happen
- Auditor: The person assigned to the task of auditing the control. This person is required to periodically audit the control to ensure that it is still relevant and is being carried out appropriately, in liaison with responsible/accountable person(s).

Potential Controls

The decision on potential controls should be reviewed based on a four stage approach:

- Decision on Potential Control: This is the decision on whether or not TIDC will implement the potential or nominated control. There may be additional Potential Controls that can be added to this table.
- How: Possible method(s) for implementing the potential control that needs to be researched, tested and verified by the designated person
- By Who: The person assigned the task of researching, testing and verifying the potential control. Ultimately, this person decides whether or not the potential control can and will be implemented.
- By When: A target date for a decision on implementation of the potential control.

Table B.1 (see over) lists the current (C) and Potential Controls (PC) that were assigned in the workshop to mitigate the risk of various root causes for an incident of an ethane release from the pipeline

There may be additional controls and/or Potential Controls that can be added to this table.

[Template to be populated as the project definition phase progresses]

TABLE B.1 FAULT MODE CONTROL TABLE					EXISTING CONTROLS						POTENTIAL CONTROLS			
												ACTION CHECKLIST		
#	REF	FAULT MODE	AREA	NATURE OF CONTROL	IMPLEMENTATION METHOD	RELEVANT CODES, STANDARDS, PROCEDURES, MANUALS, etc	RESPONS-IBILITY	ACCOUNT-ABILITY	AUDITOR	AUDIT OF CONTROLS (Assessment of the adequacy of controls)	DECISION ON POTENTIAL CONTROL	HOW	BY WHO	BY WHEN
3.0	**Ethane gas cloud forms**	**Ethane in the Pipe**		**PC: Empty pipe of ethane (though this would take a significant period of time)**	**I: Plant shut down and flare pipe content**									
3.1	**Ethane gas cloud forms**	**Pipe failure (eg rupture, holing)**		C: Appropriate Safe Working Method Statements (SWMS)	I: Procedures written and meetings held									
3.7	**Ignition**	**Train system**		**PC: Shut down rail network**	**I: Crisis Mgmt Plan involving rail network (eg power/signals)**									
4.2	**Pipe failure (eg rupture, holing)**	**Accelerated corrosion due to electrical currents**		C: Continuous monitoring of stray currents	I: Gorodok/Alinta monitoring system in place									
4.2	**Pipe failure (eg rupture, holing)**	**Accelerated corrosion due to electrical currents**		C: Risk avoidance	I: Risk assessment of stray current impact on pipe determined pipe route									
4.3	**Pipe failure (eg rupture, holing)**	**External fire (eg Vehicle, building, vegetation)**		C: Relevant fire control procedures	I: Incident Control Plan agreed with Emergency Services									
4.3	**Pipe failure (eg rupture, holing)**	**External fire (eg Vehicle, building, vegetation)**		C: Crisis Management Plan, contact details	I: 10 min Plan									

TABLE B.1 FAULT MODE CONTROL TABLE					EXISTING CONTROLS						POTENTIAL CONTROLS			
												ACTION CHECKLIST		
#	REF	FAULT MODE	AREA	NATURE OF CONTROL	IMPLEMENTATION METHOD	RELEVANT CODES, STANDARDS, PROCEDURES, MANUALS, etc	RESPONS-IBILITY	ACCOUNT-ABILITY	AUDITOR	AUDIT OF CONTROLS (Assessment of the adequacy of controls)	DECISION ON POTENTIAL CONTROL	HOW	BY WHO	BY WHEN
5.1	Penetration from external mechanical force	Enough force from impact to damage pipe		**C: Initial design & construction of pipeline protection (eg concrete cover etc)**										
5.2	Subsidence	Work causes large enough subsidence		C: Use experienced site foreman to supervise works	I: Review of drawings and area before work commences. Do not allow heavy plant at top of cutting / embankment									
5.2	Subsidence	Work causes large enough subsidence		C: Design to appropriate standards	I: Review geotechnical information and design slopes to the appropriate angles									
5.4	Accelerated corrosion due to electrical current results in pipe failure	Dropped 33kV cable		C: Appropriate Safe Working Method Statements (SWMS)	I: Procedures written and meetings held									
6.16	Attack on pipe	Opportunity for sabotage		C: Minimise unauthorised access to documentation and site in order to reduce the potential for sabotage										
7.0	Impact from machinery	Digging, piling or drilling		C: Indicate position of pipeline	I: Mark out pipeline and 2m hazard zone									
7.4	Vibration	Hammering of piles		C: Vibration minimisation	I: Use appropriate technology to minimise vibrations in ground									

TABLE B.1 FAULT MODE CONTROL TABLE					EXISTING CONTROLS						POTENTIAL CONTROLS			
												ACTION CHECKLIST		
#	REF	FAULT MODE	AREA	NATURE OF CONTROL	IMPLEMENTATION METHOD	RELEVANT CODES, STANDARDS, PROCEDURES, MANUALS, etc	RESPONS-IBILITY	ACCOUNT-ABILITY	AUDITOR	AUDIT OF CONTROLS (Assessment of the adequacy of controls)	DECISION ON POTENTIAL CONTROL	HOW	BY WHO	BY WHEN
7.5	Vibration	Vibratory compaction equipment		C: Geotechnical risk assessment	I: Consideration of impact of vibratory construction equipment and no adverse impact inside 2m zone. Do not use oversized machinery									
8.0	Digging, piling or drilling	Authorised digging impacts pipe		C: 2m/5m Hazard zone, Gorodok	I: All site foremen to be aware of Gorodok requirements									
8.1	Digging, piling or drilling	Unauthorised digging impacts pipe with sufficient force / equipment, angle at location of pipeline		C: Access control	I: Contractor induction, site security									
8.1	Digging, piling or drilling	Unauthorised digging impacts pipe with sufficient force / equipment, angle at location of pipeline		C: Interface co-ord meetings	I: Meetings two weekly, review of hazard log & updated									
8.2	Heavy load crushing pipe	Crane outrigger		C: Use experienced site foreman to supervise works	I: Review SWMS, and position crane at a safe distance from pipeline									

TABLE B.1 FAULT MODE CONTROL TABLE					EXISTING CONTROLS						POTENTIAL CONTROLS			
												ACTION CHECKLIST		
#	REF	FAULT MODE	AREA	NATURE OF CONTROL	IMPLEMENTATION METHOD	RELEVANT CODES, STANDARDS, PROCEDURES, MANUALS, etc	RESPONS-IBILITY	ACCOUNT-ABILITY	AUDITOR	AUDIT OF CONTROLS (Assessment of the adequacy of controls)	DECISION ON POTENTIAL CONTROL	HOW	BY WHO	BY WHEN
8.3	Heavy load crushing pipe	Movement of heavy load		C: Safe Work Methods Statements	I: Prevent any vehicles >8 tonnes axle load within 2m									
8.3	Heavy load crushing pipe	Movement of heavy load		C: Guarding of pipe with concrete protection slabs	I: Appropriate concrete slabs are placed over all pipes within 2m of hazard zone									
9.0	Authorised digging impacts pipe	Digging in incorrect spot		C: Continuous physical surveillance	I: Formal signoff of inspections									
9.0	Authorised digging impacts pipe	Digging in incorrect spot		C: Monthly risk mgmt review by snr mgmt	I: Alinta, TIDC, Gorodok, Contractor - formal meeting between mgmt									
9.1	Authorised digging impacts pipe	Pipe in digging zone		C: Risk identification of pinch spots	I: Documentation of points and workshops/meetings to identify									
9.1	Authorised digging impacts pipe	Pipe in digging zone		C: Meetings with Alinta/Gorodok	I: Fortnightly meetings									
10.0	Digging in incorrect spot	Flawed design & construction methodology		C: Monitoring - Alinta, Gorodok	I: High level risk assessment, detailed mgmt plan, design endorsement by third party, signoff, onsite attendence to ensure implementation									
10.1	Digging in incorrect spot	Wrong information (eg pipe location, wrong version of drawing used)		C: Identification of pipe location to +/- 250mm	I: Pipe location verified through using current & historical PIG data, using inertia navigation system, planning, pot									

TABLE B.1 FAULT MODE CONTROL TABLE					EXISTING CONTROLS						POTENTIAL CONTROLS			
												ACTION CHECKLIST		
#	REF	FAULT MODE	AREA	NATURE OF CONTROL	IMPLEMENTATION METHOD	RELEVANT CODES, STANDARDS, PROCEDURES, MANUALS, etc	RESPONS-IBILITY	ACCOUNT-ABILITY	AUDITOR	AUDIT OF CONTROLS (Assessment of the adequacy of controls)	DECISION ON POTENTIAL CONTROL	HOW	BY WHO	BY WHEN
					holing (vibration, EMF)									
10.1	Digging in incorrect spot	Wrong information (eg pipe location, wrong version of drawing used)		C: Quality/document control systems	I: Version control, appropriate QA protocols									
10.2	Digging in incorrect spot	Information interpreted incorrectly		C: Communications process	I: Team meetings, supervisor briefings, shift briefings									
10.2	Digging in incorrect spot	Information interpreted incorrectly		C: Competency of engineers & supervisors	I: Experience, peer review, monitoring by engineers, safe working method statements SWMS									
10.4	Digging in incorrect spot	Operator unfit to undertake work causes error		C: HR systems										
10.7	Train hits disturbance caused by work	Disturbances on track not fixed		C: Implementation of approved track changes/design	I: P53 check to ensure track is ready for use (eg rail integrity, foreign objects removed)									
10.7	Train hits disturbance caused by work	Disturbances on track not fixed		C: TIDC independent reliability check	I: Specific TIDC employee who makes their own inspection									

TABLE B.1 FAULT MODE CONTROL TABLE					EXISTING CONTROLS						POTENTIAL CONTROLS			
												ACTION CHECKLIST		
#	REF	FAULT MODE	AREA	NATURE OF CONTROL	IMPLEMENTATION METHOD	RELEVANT CODES, STANDARDS, PROCEDURES, MANUALS, etc	RESPONS-IBILITY	ACCOUNT-ABILITY	AUDITOR	AUDIT OF CONTROLS (Assessment of the adequacy of controls)	DECISION ON POTENTIAL CONTROL	HOW	BY WHO	BY WHEN
10.8	Train dynamic appropriate to derail	Speed of train appropriate for derailing		PC: Speed limits in construction work zones	PC: Speed limits in construction work zones									
11.2	Measuring equipment failure	Incorrect calibration		C: Base line & sensitivity testing	I: Checking instrument before actual use (eg use of pilot hole)									
11.2	Measuring equipment failure	Incorrect calibration		C: QA on instrument	I: eg NATA certified or equivalent									
11.3	Measuring equipment failure	External influences causing measuring error		C: Review environmental conditions before commencing										
11.4	Measuring equipment failure	Incorrect base line		C: Base line & sensitivity testing	I: Checking instrument before actual use (eg use of pilot hole)									
12	Flaw leads to digging in wrong spot	Flawed scope		C: Scope control procedures	I: Scope to be reviewed by senior management									
12.1	Flaw leads to digging in wrong spot	Design error		C: K2R control - avoid intrusion works near pipeline (ie soil, nails, bored piles, foundations)										
12.1	Flaw leads to digging in wrong spot	Design error		C: Independent design verification and multidisciplinary design checking	I: Accredited (Int or Ext) Engineering Authority approval									

TABLE B.1 FAULT MODE CONTROL TABLE					EXISTING CONTROLS						POTENTIAL CONTROLS			
												ACTION CHECKLIST		
#	REF	FAULT MODE	AREA	NATURE OF CONTROL	IMPLEMENTATION METHOD	RELEVANT CODES, STANDARDS, PROCEDURES, MANUALS, etc	RESPONS-IBILITY	ACCOUNT-ABILITY	AUDITOR	AUDIT OF CONTROLS (Assessment of the adequacy of controls)	DECISION ON POTENTIAL CONTROL	HOW	BY WHO	BY WHEN
12.2	Flaw leads to digging in wrong spot	Incorrect design implementation		C: Critical review	I: K2R control - avoid horizontal drilling within hazard zones									
13	Design error	Wrong standards		C: Industry practice	I: Keep controlled copies of all current standards / guidelines in agreed location									
13.1	Design error	Wrong assumptions / standards / guidelines		C: Independent checks / peer review	I: Review and challenge assumptions									
13.2	Design error	Lack of competency from design team		C: Review HR requirements	I: Interview potential employees to determine appropriate experience									

Appendix C

Fault Tree Analysis

The fault tree can be used as a mathematical model to calculate the probability of the event occurring from estimated input values known as fault modes.

Australian Standard AS/NZS 3931:1998 Risk Analysis of Technological System - Application Guide says in Section 7 Risk Analysis Methods 7.2 Selection Of Methods –

"In general terms, a suitable method should exhibit the following characteristics:

1. Scientifically defensible and appropriate to the system under consideration.
2. Should provide results in a form which enhances understanding of the nature of the risk and how it can be controlled.
3. Should be capable of use by a variety of practitioners in a manner that is traceable, repeatable and verifiable."

The fault tree method fulfils those criteria. The description given of the fault tree technique in AS/NZS 3931:1998 is provided in the following section.

Description and Limitations of Fault Tree

Fault Tree Analysis: Hazard Identification and Frequency Technique which starts with the undesired event and determines all the ways in which it could occur. These are displayed graphically.

In this study, the use of the fault tree analysis to understand how a loss would occur is appropriate according to AS/NZS 3931. The study is designed to ensure all "root causes" are fully understood, documented, and that control mechanisms are in place.

Further in the standard, on Page 23 in Section 8.3 Fault Tree Analysis (FTA) – "FTA is a technique which can be either qualitative or quantitative." In this study, the resulting

fault tree was than used to quantify the "top event" by assigning probabilities to all root causes.

Fault Tree Construction

There are three main components, which are used to construct a fault tree:

Figure 1: Fault Tree Component, "The Top Event"

The "top event" is the failure or event that is to be studied.

Figure 2: Fault Tree Component, "The And Gate" and "The Or Gate"

The "and gate" and the "or gate" are the two elements of the fault tree which allow the logic of the diagram to be developed. An "and gate" produces the understanding that the elements attached to the "and gate" must all occur for the outcome event to occur. An "or gate" asserts that for the outcome event to result, any one or more of the elements attached to the gate could take place.

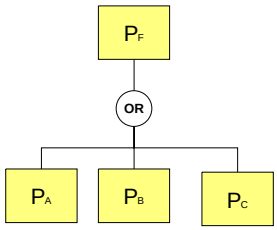
Fault Tree Analysis begins with a top-level undesired event and works down to identify the initiating events that could cause the unwanted outcome. By multiplying probabilities at "AND Gates" and adding probabilities at "OR Gates" the probability of the "top event" can be determined.

Fault Tree Quantification

The rules and conventions of Fault Tree quantification, as outlined by P.L. Clemens (2002), are as follows:

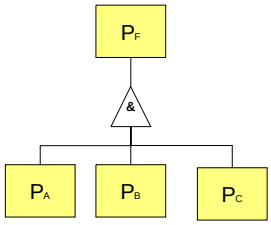
At 'OR' Gates:

$\mathbf{P_F = P_A + P_B + P_C} - P_AP_B - P_AP_C - P_BP_C + P_AP_BP_C$, or:
$\mathbf{P_F = P_A + P_B + P_C}$ (approximate)



At 'AND' Gates:

$\mathbf{P_F = P_A \times P_B \times P_C}$



Appendix D

Stochastic Modelling - Modelling Uncertainty

Monte Carlo Simulations

Monte Carlo simulations can be used as a technique for modelling uncertainty ie. Stochastic Modelling. Monte Carlo simulations use random variable generation weighted to a probability density function to determine an input value. Samples are more likely to be drawn in areas which have higher probabilities of occurrence. In cumulative distributions each Monte Carlo sample uses a new random number between 0 and 1. With enough iterations, Monte Carlo sampling "recreates" the input distributions through sampling.

During a simulation a probability distribution which describes the range of possible values for the input is substituted for its original single fixed value. When a risk analysis is run, a spreadsheet is calculated over and over again where each re-calculation is an "iteration". After each iteration the spreadsheet is recalculated with a new set of sampled values and a new possible result is generated for the output probability. A distribution of possible outcomes is created by taking all the possible output values generated, analysing them and calculating statistics on how they are distributed across their minimum-maximum range.

Sensitivity Analysis

Stepwise regression can be used as a method for estimating sensitivity between input and output data. Regression is simply another term for fitting data to a theoretical equation. In the case of linear regression, the input data is fitted to a line.

Stepwise regression is a technique for calculating regression values with multiple input values. Other techniques exist for calculating multiple regressions, but the stepwise regression technique is preferable for large numbers of inputs since it removes all variables that provide an insignificant contribution from the model.

The coefficients listed in the sensitivity report are normalised regression coefficients associated with each input. A regression value of 0 indicates that there is no significant relationship between the input and the output, while a regression value of 1 or -1 indicates a 1 or -1 standard deviation change in the output for a 1 standard deviation change in the input.

The model

For the purposes of this project, Monte Carlo simulations were used to carry out the stochastic modelling of the fault tree. It was assumed that the probability of each input is based on a log-normal distribution and the 99% confidence interval is twice the mean, ie if the mean is 1 event every 10 years (probability of 0.1) then the 99 percentile is 1 event every 5 years (probability of 0.2).

Appendix E

Acceptable and Tolerable Risk levels

Individual Risk

Adequate levels of Individual Risk (safety) can be addressed by applying the relevant risk criteria specified in the Department of Urban Affairs and Planning Risk Criteria.

"All activities have an associated level of risk. It is not possible to eliminate that risk unless the activity itself is eliminated. The criteria are therefore based on the concept of a residual risk, the acceptability of which should be established in relation to various land uses" (Department of Urban Affairs and Planning, 1997:2).

The relevant risk criteria from the NSW Department of Urban Affairs and Planning (1997) are listed in Table E.1, overleaf.

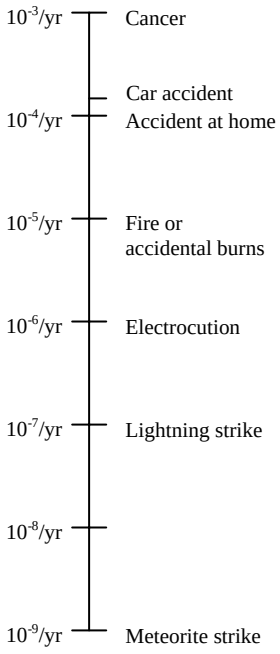


Figure E.1 Individual fatality risk from various causes (NSW DUAP, 1997)

Table E.1: Risk Criteria

Risk Criteria	Fatality Criteria
Hospital Area Risk Criteria Definition of Hospital Area: Hospitals, schools, child-care facilities and old age housing	Hospital areas should not be exposed to individual fatality risk levels in excess of half in a million per year (0.5×10^{-6} per year).
Residential Area Risk Criteria Definition of Residential Area: Residential developments and places of continuous occupancy, such as hotels and tourist resorts	Residential areas should not be exposed to individual fatality risk levels in excess of one in a million per year (1×10^{-6} per year).
Commercial Area Risk Criteria Definition of Commercial Area: Commercial developments, including offices, retail centres, warehouses with showrooms, restaurants and entertainment centres	Commercial areas should not be exposed to individual fatality risk levels in excess of five in a million per year (5×10^{-6} per year).
Park Area Risk Criteria Definition of Park Area: Sporting complexes, parks and active open space area	Park areas should not be exposed to individual fatality risk levels in excess of ten in a million per year (10×10^{-6} per year).
Industrial Area Risk Criteria Definition of Industrial Area: adjacent industrial areas which involve operations of similar risk levels	Industrial areas should not be exposed to individual fatality risk levels in excess of fifty in a million per year (50×10^{-6} per year).

Appendix F

Industry data

As part of this project, we have sought to utilise industry data where available for use in developing the fault tree. This report also includes industry data for comparative analysis as appropriate and for verification of the contributing causes for pipeline failure.

Pipeline failure – causes

Based on analysis of Reportable Incidents[1] filed with the US department of Transportation (DOT) for data collected between 1970 and 1984, damage from force outside the pipeline is the primary cause of natural gas pipeline failures in the USA. The second and third causes of line service failures as material failure and corrosion.

Over the 14.5 year period, 5,872 reportable service incidents occurred on natural gas transmission and gathering lines. The primary cause of these service failures was:

Cause	**Number**	**%**
Outside force	3144	53.5%
Material failure	990	16.9%
Corrosion	972	16.6%
Other	437	7.4%
Construction defect	284	4.8%
Construction or material	45	0.8%

[1] Reportable Incidents were defined by the DOT's Office of Pipeline Safety Regulation (OPSR) as those which result in death or injury requiring hospitalization, required the removal of any segment of transmission pipeline, resulted in gas ignition, caused an estimated US$5,000 or more of damage, involved a leak requiring repair, involved a test failure or was significant in the judgement of the operator even through it did not meet any of the above criteria.

Analysing the 'Outside force' incidents in more detail, the causes were broken down as follows:

Cause	**%**
Equipment operated by outside party	67.1%
Earth movement	13.3%
Weather	10.8%
Equipment operated by, or for, pipeline operator	7.3%
Other	1.5%

67% of the outside force incidents result from equipment operated by an outside party. This clearly indicates that many incidents result from human error and miscalculations and are therefore potential preventable.

Analysis of the data on the depth of burial provides some further insight into the outside force incidents:

Location of pipe (ie depth of burial)	**% of outside force incidents**
Above ground piping	29%
Buried 6 to 12 inches	13%
Buried 12 to 24 inches	17%
Buried 24 to >60 inches	41%

It was concluded that deep burial provides no significant amount of protection increase against outside-force incidents.

Source: Encyclopaedia of Chemical Processing and Design – Pipeline Failure

European Gas pipeline Incident data Group

In 1982 six European gas transmission system operators took the initiative to gather data on the unintentional releases of gas in their pipeline transmission systems. This co-operation was formalised by the setting up of EGIG (European Gas pipeline Incident data Group). Now EGIG is a co-operation between a group of twelve major gas transmission system operators in Western Europe and is the owner of an extensive gas pipeline-incident database.

The creation of this extensive pipeline-incident database (1982) has helped pipeline operators to demonstrate the safety performances of Europe's gas pipelines. This information has helped the pipeline operators to improve safety in their gas pipeline transmission systems.

Considering the number of participants, the extent of the pipeline systems and the exposure period involved (from 1970 onwards for most of the companies), the EGIG database is a valuable and reliable source of information. The regional differences are not taken into account so that the result of the database presents an average of all participating companies.

Overview developments in failure frequencies - (Updated at December 2005)

An extensive analysis of EGIG incident data[2] covering the period 1970 to 2004 has lead to the following overview of failure frequencies:

Timescale		**No. of incidents**	**Total exposure (kmyr)**	**Frequency (Incidents per 1000 kmyr)**
1970-2004	6th EGIG report	1123	2.77 v 10^6	0.41
2000-2004	Last 5 years	100	0.57 x 10^6	0.17
2004	Last year	23	0.12 x 10^6	0.19

During the 37th meeting of the EGIG group, EGIG came to the following conclusions:

- The statistics of incidents collected in the database give reliable failure frequencies. The overall incident frequency is equal to 0.41 incidents per year per 1,000 km over the period 1970 to 2004
- The 5 year moving average overall failure frequency, which represents the average incident frequency over the past 5 years, equals 0.17 per year per 1,000 km. This frequency is almost 5 times lower than the one reported in the first years of the data base (1970-1974)
- The failure frequencies have been reducing consistently over the years, although they recently tend to stabilize
- The major cause of incidents remains:
  - external interference (50% of all incidents)
  - construction defects/material failures (17%), and
  - corrosion (15%)
- Of the external interference activities (which account for 50% of incidents), 39% involve excavators for digging, 8% through drainage works and 8% through public works.

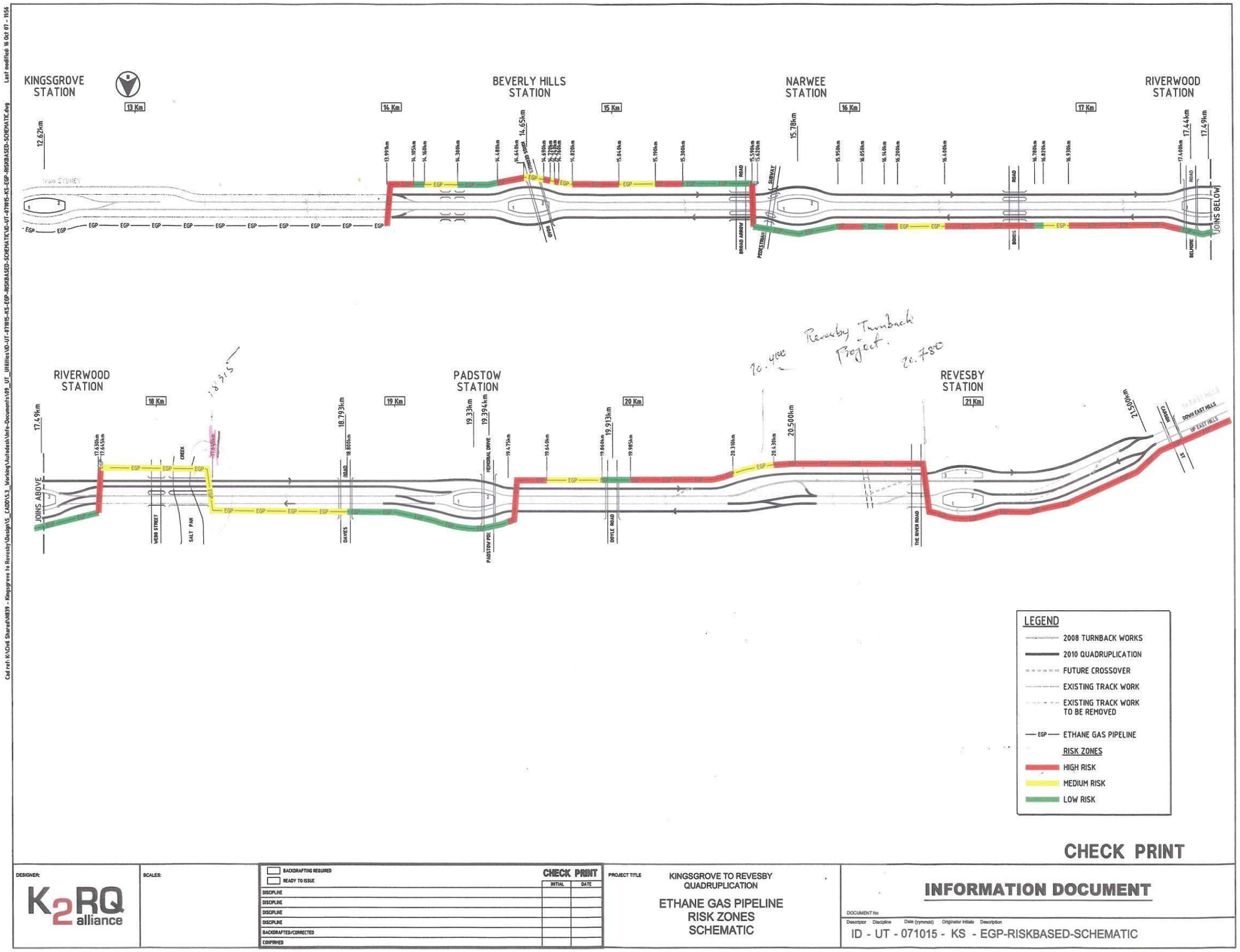
[2] The required criteria for an incident to be recorded in the EGIG database are the following: the incident must lead to an unintentional gas release, the pipeline must fulfil the following conditions – be made of steel, be onshore, to have a design pressure higher than 15 bar, to be located outside the fences of the installations

- The relatively high contribution of external inference emphasises its importance to pipeline operators and authorities
- External interference incidents are characterised by potentially severe consequences (holes and ruptures).

Appendix G

Pipeline Risk Ratings

See overleaf.


KINGSGROVE STATION
BEVERLY HILLS STATION
NARWEE STATION
RIVERWOOD STATION
RIVERWOOD STATION
PADSTOW STATION
REVESBY STATION
JOINS ABOVE
JOINS BELOW
EGP
LEGEND
2008 TURNBACK WORKS
2010 QUADRUPLICATION
FUTURE CROSSOVER
EXISTING TRACK WORK
EXISTING TRACK WORK TO BE REMOVED
EGP ETHANE GAS PIPELINE
RISK ZONES
HIGH RISK
MEDIUM RISK
LOW RISK
CHECK PRINT
DESIGNER:
K2RQ alliance
SCALES:
BACKDRAFTING REQUIRED
READY TO ISSUE
CHECK PRINT
INITIAL DATE
DISCIPLINE
BACKDRAFTED/CORRECTED
CONFIRMED
PROJECT TITLE
KINGSGROVE TO REVESBY QUADRUPLICATION
ETHANE GAS PIPELINE RISK ZONES SCHEMATIC
INFORMATION DOCUMENT
DOCUMENT No
ID - UT - 071015 - KS - EGP-RISKBASED-SCHEMATIC
18 Oct 07

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