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Validation of Models Implemented in the PIRAMID™ Prioritization Software

PIRAMID Technical Reference Manual No. 10.0

Confidential to C-FER's Pipeline Program Participants

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C-FER Technologies Inc.

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EXECUTIVE SUMMARY

The objective of this project was to provide a mechanism for the collective assessment, by companies and government agencies participating in the *PIRAMID*™ development initiative, of the degree to which the pipeline system prioritization modules provide repeatable results that are consistent with available historic data and expert engineering judgment. The project also served to identify areas where improvement is desirable in terms of the accuracy and/or repeatability of the models.

The specific program modules evaluated include *PIRAMID*™ Onshore Prioritization and *PIRAMID*™ Offshore Prioritization (Version 1.4 releases dated February 1998). The approach developed to validate the models implemented in these programs was to have C-FER personnel use the software to analyse representative segments of real pipelines based on information supplied by participating operating companies (or supplied on behalf of operating companies by participating government agencies). The results obtained for the line segments submitted were then processed, summarized and presented to participants for review. A one-day workshop, involving all current program participants, was then held to provide a forum for a discussion of the results obtained. The workshop findings form the basis for the conclusions and recommendations presented herein.

Note that it was originally intended that both gas and liquid pipeline systems would be considered in this validation exercise. However, C-FER did not receive the required data for liquid lines. The final work scope was therefore restricted to an evaluation of the models applicable to natural gas pipeline systems only. Given this restriction the parts of the consequence estimation model associated with the estimation of liquid spill volumes and the financial and environmental impact of persistent liquid spills were not evaluated in this project.

In total, 19 sections of onshore natural gas pipeline, having varying perceived combinations of low and high failure probability and low and high failure consequences, were submitted for analysis. For offshore pipelines, however, only a single gas pipeline was submitted for analysis, and while the offshore line was reported to contain sections corresponding to low and high estimates of the likelihood and consequences of failure, these distinct sections were not explicitly delineated. To exercise the offshore risk estimation models over a range of conditions and provide a basis for discussion, the line was divided into four representative sections. Selected line attributes were then modified, and the resulting offshore line sections were then subjectively classified by C-FER as to both the probability of failure and the severity of failure consequences.

The general findings of this model validation process are as follows:

- The overall risk rankings obtained using the prioritization models, for both onshore and offshore pipelines, are broadly consistent with expectations.

- Sections subjectively assessed to have relatively low and high probabilities of failure were correctly delineated and both low and high consequence areas were clearly reflected in the total risk estimates.

- The ranking of individual pipelines by the estimated risks levels associated with individual failure causes was found to correctly target the failure mechanisms expected to contribute most to the failure potential for the lines in question.

In addition, it was found that the consequence estimation models currently implemented appear to provide a more accurate representation of the true range of failure consequences (*i.e.*, several orders of magnitude) than available alternative models, most of which are based on subjective characterizations of failure impact. Since ranking models that underestimate the range of failure consequences will tend to produce a ranking that is skewed towards high probability sections, the implication is that the *PIRAMID*™ prioritization models provide a more balanced characterization of operating risk.

With specific regard to the prioritization models developed for onshore pipeline systems, some areas of concern were identified, particularly with regard to the perceived accuracy of models developed for estimating the probabilities of failure due to external metal loss corrosion, stress corrosion cracking and mechanical damage. In terms of repeatability issues, some model input parameters were identified as having the potential for differing interpretations of what is to be specified.

Specific comments on, and suggestions for improvements to, the probability and consequence estimation models applicable to onshore pipelines, as provided by companies and agencies participating in the *PIRAMID*™ development initiative, are summarized in Section 4.2 of this report. The listed comments pertaining to the accuracy and repeatability of the probability estimation models are currently being addressed in a follow-on project in the *PIRAMID*™ development program (Project 8 in the approved works scope for the 1998 budget year), which involves revisions to the prioritization models. The issues raised pertaining to the consequence estimation models are being addressed in another follow-on project (Project 5 in the approved works scope for the 1999 budget year), the scope of which encompasses general *PIRAMID*™ model and software improvements.

Note that no specific comments were received on the probability and consequence estimation models associated with the offshore pipeline system prioritization software. This stems from the fact that no offshore pipeline operators were available to participate in the validation process (*i.e.*, test cases for offshore pipelines were submitted by operating companies that do not belong to the *PIRAMID*™ development program through the US Minerals Management Service). It is, therefore, recommended that accuracy and repeatability issues, as they relate to the models developed for offshore pipelines, be revisited in the near future when more direct involvement of offshore pipeline operating companies can be obtained.

1. INTRODUCTION

1.1 Rationale

During the course of the *PIRAMID*™ program development initiative, the adopted physical and probabilistic models are tested to ensure that, from C-FER's perspective, they produce results that are both reasonable and sufficiently accurate for their intended purpose. The software is also tested to verify that the chosen methods and models have been correctly implemented.

Now that some of the program modules have passed this initial stage of verification and been delivered to the participants as operational (non-beta) versions, it is possible to undertake additional testing aimed at validating the *PIRAMID*™ methodology from a broader perspective. The purpose of this follow-on work is to provide a way for both C-FER and companies participating in the *PIRAMID*™ program development initiative to assess how well the *PIRAMID*™ approach performs for actual pipeline systems with respect to the following criteria:

- Reasonableness. Are the results obtained consistent with historic trends and engineering judgment?
- Repeatability. Would different users obtain similar answers if they analyzed the same pipeline?

In addition to the potential for identifying possible improvements to the program modules in the above areas, this validation process will result in a better understanding by the participants of how to use *PIRAMID*™ effectively and ultimately improved confidence in the final product.

1.2 Scope and Objectives

The specific objective of this project was to provide a mechanism for the collective assessment, by companies and government agencies participating in the development initiative, of the degree to which the *PIRAMID*™ pipeline system prioritization modules provide repeatable results that are consistent with available historic data and expert engineering judgment. Current releases of both onshore and offshore versions of the prioritization software are addressed in this exercise (*i.e.*, *PIRAMID*™ Onshore Prioritization and *PIRAMID*™ Offshore Prioritization, Version 1.4 released February 1998). The project also served to identify areas where improvement is desirable in terms of the accuracy and/or repeatability of the models. It is intended that the improvements identified through this validation process will form the basis for subsequent software-updating projects.

The *PIRAMID*™ prioritization modules rank pipeline segments based on their calculated level of operating risk, where the operating risk is given by a probability weighted estimate of the

consequences of line failure. Both probability (*i.e.*, failure frequency) and consequence estimation models are therefore addressed in this validation process.

Note that it was originally intended that both gas and liquid pipeline systems would be considered in this validation exercise. However, C-FER did not receive the required data for liquid lines. The final work scope was therefore restricted to an evaluation of the models applicable to natural gas pipeline systems only. Given this restriction the parts of the consequence estimation model associated with the estimation of liquid spill volumes and the financial and environmental impact of persistent liquid spills were not evaluated in this project.

1.3 Approach

The approach developed to meet the project objectives was to have C-FER personnel use the pipeline system prioritization software to analyse representative segments of real pipelines based on information supplied by participating operating companies (or supplied on behalf of operating companies by participating government agencies). The results obtained for the line segments submitted were then processed, summarized and presented to participants for review. A one-day workshop, involving all current program participants, was then held to provide a forum for a discussion of the results obtained. The workshop findings form the basis for the conclusions and recommendations presented herein.

1.4 Organization of Report

The proposed test case matrix and a description of the pipeline segments submitted for analysis by the participating companies and agencies is given in Section 2.0. The results obtained from an analysis of the individual pipeline segments using the *PIRAMID*™ prioritization software is summarized in Section 3.0. A discussion of the results obtained, including a summary of the workshop findings, is provided in Section 4.0, and the conclusions and recommendations developed from those findings are given in Section 5.0.

2. TEST CASES

2.1 Overview

To provide a basis for an assessment of the accuracy and repeatability of the probability and consequence estimation models employed in the prioritization programs, over a sufficiently wide range of conditions, a test matrix was devised that consisted of two broad categories of pipelines. The first category consisted of relatively large diameter lines, and the second consisted of relatively small diameter lines. Within each diameter category, four cases were defined corresponding to the four possible combinations of low and high values of the likelihood of failure and severity of failure consequences. The resulting eight-cell test matrix is as shown in Figure 2.1.

To populate the test matrix, each participating company was asked to submit for analysis a number of large and small diameter pipeline sections. For consistency a nominal diameter of 914 mm (36 in) was chosen as the preferred size for large diameter sections and a nominal diameter of 305 mm (12 in) was selected as the preferred size for small diameter sections. Participants were also ask to indicate, based on experience and judgement, whether the likelihood of failure and consequences of failure was perceived to be high or low, for each line section submitted.

Note that in the context of this validation study (and in the context of the *PIRAMID*™ methodology in general) a *section* of pipeline is defined as a length of line along which each attribute (*e.g.*, age, coating type, land use) can be assumed to be essentially uniform.

2.2 Onshore Pipelines

In total, 19 pipeline sections from four different operating companies were submitted for analysis. In the large diameter pipeline category, ten line sections were submitted having diameters ranging from 914 mm (36 in) to 1067 mm (42 in). In the small diameter category, nine lines were submitted with diameters ranging from 273 mm (10 3/4 in) to 457 mm (18 in). At least one line section populated each cell in the proposed test matrix (see Figure 2.2a).

A summary of key parameters associated with the line sections submitted for analysis is given in Table 2.1. Note that each line section is identified by an alphanumeric code. The section name and the associated operator are not given to protect the confidentiality of the information submitted by companies participating in the validation study. (A version of Table 2.1 containing the section and operator names corresponding to the alphanumeric section labels, is being provided to participants under separate cover and additional copies are available from C-FER at participant request.)

Test Cases

The set of line attributes that must be specified for an analysis using the *PIRAMID*™ Onshore Prioritization program is summarized in Table 2.2. (An explanation of the intended meaning of each pipeline attribute, an indication of the probability and consequences estimation models that make use of each attribute, and guidance on how each attribute is to be defined, is given in Appendix A. Note that this information is an extract from the software program User's Guide and is reproduced here for the convenience of the reader.) The specific values of the line attributes for each line section analysed are summarized in Table 2.3.

2.3 Offshore Pipelines

A single 273 mm(10 ¾ in) diameter gas pipeline was submitted (on behalf of the operator by a participating government agency) for analysis. While the line was reported to contain sections corresponding to low and high estimates of the likelihood and consequences of failure, these distinct sections were not explicitly delineated. To exercise the offshore risk estimation models over a range of conditions and provide a basis for discussion, the line was divided into four representative sections. Selected line attributes were then modified, and the resulting offshore line sections were then subjectively classified by C-FER as to both the probability of failure and the severity of failure consequences. The attribute adjustments were made to ensure that at least one section populated each cell in the proposed test matrix for a single diameter category (see Figure 2.2b). The line as originally submitted, consisting of a length weighted blend of the three attribute-consistent line sections, was also analysed for comparison purposes.

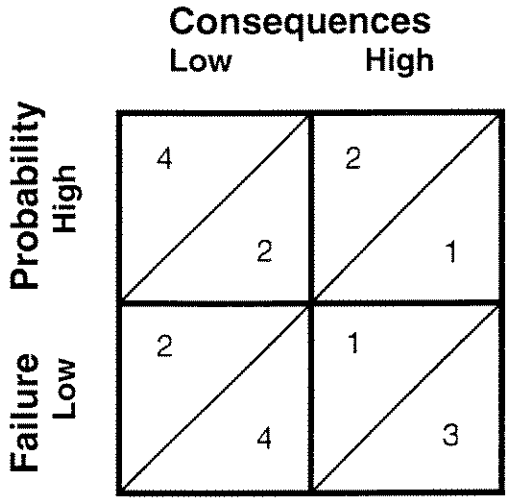
A summary of key parameters associated with the line sections generated from the pipeline that was submitted for analysis is given in Table 2.4. As for onshore pipelines note that the section name and the associated operator are not given in the table to protect the confidentiality of the information submitted by companies participating in the validation study. (A version of Table 2.4 containing the section and operator names corresponding to the alphanumeric section labels, is being provided to participants under separate cover and additional copies are available from C-FER at participant request.)

The set of line attributes that must be specified for an analysis using the *PIRAMID*™ Offshore Prioritization program is summarized in Table 2.5. (An explanation of the intended meaning of each offshore pipeline attribute, an indication of the probability and consequences estimation models that make use of each attribute, and guidance on how each attribute is to be defined, is given in Appendix B. Note that this information is an extract from the software program User's Guide and is reproduced here for the convenience of the reader.) The specific values of the line attributes for each line section analysed are summarized in Table 2.6.

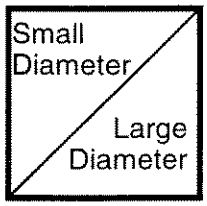
Figures and Tables

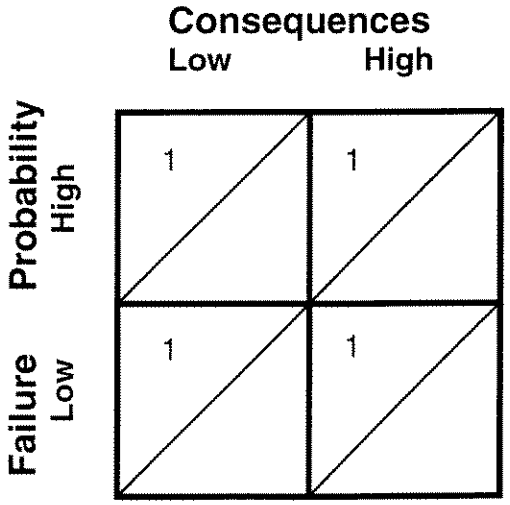
Perceived Likelihood of Failure		Perceived Severity of Failure Consequences	
		Low	High
Low	Small Diameter Range		
	Large Diameter Range		
High	Small Diameter Range		
	Large Diameter Range		

Figure 2.1 Test matrix for model validation.



a) Onshore pipelines.





b) Offshore pipelines.

Figure 2.2 Correspondence between line sections submitted and proposed test matrix.

Label	Dia.	Land Use	Probability	Consequence	Comment
A1	324	Res Urb	H	H	
A2	324	Res Rur	H	L	Probability
A3	324	Res Urb	L	H	and
A4	324	Rem Oth	L	L	Conseq.
B1	914	Res Urb	M	H	Ranking
B2	914	Rem For	H	L	Assigned
B3	914	Rem For	L	L	by Operator
B4	1067	Prk For	L	M	
C1	914	Agr	L	L	
C2	914	Res Urb/Rur	L	HJ	
C3	300	Ind	H	L	Probability
D1	914	Res Urb	L	H	and
D2	914	Rem For	L-M	L	Conseq.
D3	324	Prk For	M	L	Ranking
D4	457	Prk For	H	L	Assigned
D5	406	Agr	L-M	L	by CFER
D6	273	Res Urb	M	H	
D7	914	Prk Oth	L	L	
D8	914	Agr	L-M	L	

Table 2.1 Characterization of onshore pipeline sections analysed.

No.	Attribute Description	Attribute Name	Units ext (int)	Input Type	Required for Probability Estimation	Required for Consequenc Estimation	Analysis Preferences: Natural Gas only	HVP liquids only	LVP liquids included: consider env	LVP liquids included: suppress env
1	Pipe Diameter	PipeDia	mm (m)	S1	X	X	X	X	X	X
2	Pipe Wall Thickness	PipeWall	mm (m)	S1	X	X	X	X	X	X
3	Pipe Body Yield Strength	PipeYield	MPa (Pa)	S1	X		X	X	X	X
4	Pipe Body Seam Weld Type	SeamType		S2	X		X	X	X	X
5	Pipe Joint Type	JointType		S2	X		X	X	X	X
6	Line Age	LineAge	years	S1	X		X	X	X	X
7	Line Elevation Profile	ElevProfile	m	C1		X		X	X	X
8	Operating Pressure Profile	PressProfile	kPa (Pa)	C1	X	X	X	X	X	X
9	Operating Pressure Range	PressRange	kPa (Pa)	S1	X		X	X	X	X
10	Cumulative Number of Pressure Cycles	PressCycle		S1	X		X	X	X	X
11	Operating Temperature	LineTemp	°C (K)	S1	X	X	X	X	X	X
12	Product Flow Rate (sign denotes flow direction)	FlowRate	kg/s	S1		X	X	X	X	X
13	Line Volume (percentage of line capacity)	CapFraction	% (fraction	S1		X	X	X	X	X
14	Billing Abatement Threshold (percentage of nomina	BAT	% (fraction	S1		X	X	X	X	X
15	Product Transportation Distance	TransDist	km (m)	S1		X	X	X	X	X
16	Block Valve Spacing	ValveSpace	km (m)	S1		X	X	X	X	X
17	Time to Block Valve Closure	TimeClose	min (sec)	S1		X	X	X	X	X
18	Detectable Release Volume	VolDetect	cu. m.	S1		X	X	X	X	X
19	Time to Leak Detection	TimeDetect	hrs (sec)	S1		X	X	X	X	X
20	Time to Leak Stoppage (from time of detection)	TimeStop	hrs (sec)	S1		X	X	X	X	X
21	Depth of cover	Cover	m	S1	X		X	X	X	X
22	Adacent Land Use	AdjLand		S2	X	X	X	X	X	X
23	ROW Accessibility	ROWaccess		S2		X	X	X	X	X
24	ROW Condition	ROWcond		S2	X		X	X	X	X
25	ROW Patrol Frequency	ROWpatrol		S2	X		X	X	X	X
26	Notification & Response System	Notify		S2	X		X	X	X	X
27	Crossing Type / Special Terrain Features	Crossing		S2	X		X	X	X	X
28	Near Field Terrain Characteristics	NFTerrain		S2		X			X	
29	General Soil Corrosivity	SoilCorrode		S2	X		X	X	X	X
30	SCC Potential of Soil Environment	SCCPotential		S2	X		X	X	X	X
31	External Pipe Coating Type	ExtCoating		S2	X		X	X	X	X
32	External Pipe Coating Condition	CoatCond		S2	X		X	X	X	X
33	Cathodic Protection Level	CPLevel		S2	X		X	X	X	X
34	Presence of Coating Shielding	CoatShield		S2	X		X	X	X	X
35	Presence of Electrical Interference or Casing Short	Interference		S2	X		X	X	X	X
36	Product Corrosivity	ProdCorrode		S2	X		X	X	X	X
37	Ground Movement Potential	GndMovPot		S2	X		X	X	X	X
38	Pipe Fail Potential given Ground Movement	GndFailPot		S2	X		X	X	X	X
39	Surface water within 300m	SrfWater		S2		X			X	
40	Drinking Water within 5 km	DrkWater		S2		X			X	
41	Other Water within 5 km	OthWater		S2		X			X	
42	Land Use within 5 km	DirExposure		S2		X			X	
43	Sensitive Environment within 10 km	SensEnviro		S2		X			X	
44	Sensitive Groundwater within 10 km	SensGndWtr		S2		X			X	

Attribute Data Input Type

S1 all consecutive sections delineated by KP start & KP end, defined by numeric value

S2 all consecutive sections delineated by KP start & KP end, defined by text string from predefined choice list

C1 continuously varying quantity defined by numeric values at KP reference locations

Table 2.2 Line attributes required for prioritization of onshore pipelines.

No.	Line Attribute	Input Type	A1	A2	D4	D5	D6	D7	D8
1	Pipe Diameter (mm)	S1	323.9	323.9	457	406.4	273.1	914	914
2	Pipe Wall Thickness (mm)	S1	5.16	5.16	6.35	5.99	7.09	8.74	8.74
3	Pipe Body Yield Strength (MPa)	S1	290	290	414	359	359	414	448
4	Pipe Body Seam Weld Type	S2	High Quality Weld	Suspe Weld	High Quality Weld	High Quality Weld	High Quality Weld	High Quality Weld	High Quality Weld
5	Pipe Joint Type	S2	Average Quality Weld	Averag Quality W	Average Quality Weld	High Quality Weld	High Quality Weld	Average Quality Weld	Average Quality Weld
6	Line Age (years)	S1	41	41	30	21	16	30	29
7	Line Elevation Profile (m)	C1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
8	Operating Pressure Profile (kPa)	C1	5000	5000	9191	8453	7585	5695	8563
9	Operating Pressure Range (kPa)	S1	500	500	1006.6	1296.2	427.5	158.6	172.4
10	Cumulative No. of Pressure Cycles	S1	10000	10000	30	21	16	30	29
11	Operating Temperature (°C)	S1	20	20	41	13	21	28	31
12	Product Flow Rate (kg/s)	S1	10	10	73.4	53.3	21.6	182	274
13	Line Volume (percentage of line capacity)	S1	100	100	81	72	73	80	53
14	Billing Abatement Threshold (percentage of nominated volume)	S1	100	100	85	85	85	85	85
15	Product Transport. Distance (km)	S1	0	0	1000	1000	1000	1000	1000
16	Block Valve Spacing (km)	S1	12.8	12.8	32	32	32	32	32
17	Time to Block Valve Closure (min)	S1	60	60	66.7	76.2	133.3	48.5	53.3
18	Detectable Release Volume (cu.m.)	S1	2000	2000	2000	2000	2000	2000	2000
19	Time to Leak Detection (hrs)	S1	84	84	720	720	48	720	720
20	Time to Leak Stoppage - from time of detection (hrs)	S1	24	24	240	18	18	18	18
21	Depth of cover (m)	S1	1.5	1.1	0.8	0.8	0.8	0.8	0.8
22	Adacent Land Use	S2	Residential-Urban	Residentia	kland-Forested	Agricultural	Residential-Urban	Parkland-Other	Agricultural
23	ROW Accessibility	S2	Near (easy access)	Far (difficult ac	Far ifficult access)	Near (easy access)	Near (easy access)	Near (easy access)	Near (easy access)
24	ROW Condition	S2	Below Average	Poo	elow Average	Average	Above Average	Above Average	Above Average
25	ROW Patrol Frequency	S2	Monthly	Montl	Monthly	Monthly	Monthly	Monthly	Monthly
26	Notification & Response System	S2	System (limited awareness)	Syste (limite awaren	System (high awareness)	System (high awareness)	System (average awareness)	System (high awareness)	System (high awareness)
27	Crossing/Special Terrain Features	S2	Typical X-Country Conditions	Bog/Mu	pical X-Country Conditions	Typical X-Country Conditions	Typical X-Country Conditions	Typical X-Country Conditions	Typical X-Country Conditions
28	Near Field Terrain Characteristics	S2	N/A	N/A	N/A	N/A	N/A	N/A	N/A
29	General Soil Corrosivity	S2	Average (2k-5k ohm*cm)	Above Av (1k-2k oh	High 1000 ohm*cm)	Below Average (5k-10k ohm*cm)	Below Average (5k-10k ohm*cm)	Low (>10,000 ohm*cm)	Above Average (1k-2k ohm*cm)
30	SCC Potential of Soil Environment	S2	Likely Potential	Likely Po	finite Potential	Likely Potential	Unlikely Potential	Unlikely Potential	Unlikely Potential
31	External Pipe Coating Type	S2	Tape	Tap	Tape	Tape	Asphalt	Asphalt	Asphalt
32	External Pipe Coating Condition	S2	Below Average	Below Av	elow Average	Average	Above Average	Above Average	Above Average
33	Cathodic Protection Level	S2	Average	Avera	Average	Average	Average	Below Average	Average
34	Presence of Coating Shielding	S2	No	No	Yes	No	No	No	No
35	Presence of Electrical Interference or Casing Short	S2	No	No	No	No	No	No	No
36	Product Corrosivity	S2	Negligible (< 0.02 mm/yr)	Negli (< 0.02 m	Low 02-0.1 mm/yr)	Low (0.02-0.1 mm/yr)	Low (0.02-0.1 mm/yr)	Low (0.02-0.1 mm/yr)	Low (0.02-0.1 mm/yr)
37	Ground Movement Potential	S2	Negligible (<= 1 in 100k /km)	Negli (<= 1 in 10	Low 1 in 10k /km)	Low (1 in 10k /km)	Moderate (1 in 1000 /km)	Low (1 in 10k /km)	Low (1 in 10k /km)
38	Pipe Fail Potential given Ground Movement	S2	Low (<= 1 in 100)	Lov (<= 1 in	Moderate (1 in 10)	Moderate (1 in 10)	Moderate (1 in 1000 /km)	Low (<= 1 in 100)	Low (<= 1 in 100)
39	Surface water within 300m	S2	N/A	N/	N/A	N/A	N/A	N/A	N/A
40	Drinking Water within 5 km	S2	N/A	N/	N/A	N/A	N/A	N/A	N/A
41	Other Water within 5 km	S2	N/A	N/	N/A	N/A	N/A	N/A	N/A
42	Land Use within 5 km	S2	N/A	N/	N/A	N/A	N/A	N/A	N/A
43	Sensitive Environment within 10 km	S2	N/A	N/	N/A	N/A	N/A	N/A	N/A
44	Sensitive Groundwater within 10 km	S2	N/A	N/	N/A	N/A	N/A	N/A	N/A

Attribute Data Input Type

S1 all consecutive sections delineated by KP start & KP end, defined by nume

S2 all consecutive sections delineated by KP start & KP end, defined by text s

C1 continuously varying quantity defined by numeric values at KP reference lo

Label	Dia.	Land Use	Probability	Consequence	Comment
S1	273	mixed	L	M	Probability
S2	273	manned platform	M	H	& Conseq.
S3	273	shipping corridor	H	L	Ranking
S4	273	open water	L	L	Assigned
S5	273	unmanned plat.	H	M	by C-FER

Table 2.4 Characterization of offshore pipelines analysed.

No.	Attribute Description	Attribute Name	Units ext (int)	Input Type	Required for Probability Estimation	Required for Consequence Estimation	Analysis Preferences				
							Natural Gas		HVP liquids	LVP liquids included	
							no condensate	w/ condensate	only	consider env.	suppress env.
1	Pipe Diameter	PipeDia	mm (m)	S1	X	X	X	X	X	X	X
2	Pipe Wall Thickness	PipeWall	mm (m)	S1	X	X	X	X	X	X	X
3	Pipe Body Yield Strength	PipeYield	MPa (Pa)	S1	X		X	X	X	X	X
4	Pipe Joint Type	JointType		S2	X		X	X	X	X	X
5	Line Age	LineAge	years	S1	X		X	X	X	X	X
6	Pipe Orientation	Orient	deg (rad)	S1		X	X	X	X	X	X
7	Line Elevation/Depth Profile (-ve sign implies depth)	Elev	m	C1	X	X	X	X	X	X	X
8	Operating Pressure Profile	Press	kPa (Pa)	C1	X	X	X	X	X	X	X
9	Longitudinal Stress Range	StressRange	MPa (Pa)	S1	X		X	X	X	X	X
10	Cumulative Number of Longitudinal Stress Cycles	StressCycle		S1	X		X	X	X	X	X
11	Number of Pipe Free Spans	NSpan	/km (/m)	S1	X		X	X	X	X	X
12	Operating Temperature	LineTemp	°C (K)	S1	X	X	X	X	X	X	X
13	Product Flow Rate (sign denotes flow direction)	FlowRate	kg/s	S1		X	X	X	X	X	X
14	Line Volume (percentage of line capacity)	CapFraction	% (fraction)	S1		X	X	X	X	X	X
15	Billing Abatement Threshold (percentage of nominated volume)	BAT	% (fraction	S1		X	X	X	X	X	X
16	Product Transportation Distance	TransDist	km (m)	S1		X	X	X	X	X	X
17	Block Valve Spacing	ValveSpace	km (m)	S1		X	X	X	X	X	X
18	Time to Block Valve Spacing	TimeClose	min (sec)	S1		X	X	X	X	X	X
19	Detectable Release Volume	VolDetect	cu. m.	S1		X	X	X	X	X	X
20	Time to Leak Detection	TimeDetect	hrs (sec)	S1		X	X	X	X	X	X
21	Time to Leak Stoppage (from time of detection)	TimeStop	hrs (sec)	S1		X	X	X	X	X	X
22	Depth of cover	Cover		S2	X		X	X	X	X	X
23	Vessel Traffic Density	VesselDens		S2	X	X	X	X	X	X	X
24	Subsea Activity	SubSeaAct		S2	X		X	X	X	X	X
25	Seabed Environment Corrosivity	EnvCorrode		S2	X		X	X	X	X	X
26	SCC Potential of Soil Environment	SCCPot		S2	X		X	X	X	X	X
27	External Pipe Coating Type	ExtCoat		S2	X		X	X	X	X	X
28	External Pipe Coating Condition	CoatCond		S2	X		X	X	X	X	X
29	Cathodic Protection Level	CPLevel		S2	X		X	X	X	X	X
30	Product Corrosivity	ProdCorrode		S2	X		X	X	X	X	X
31	Ground Movement Potential	GndMovPot		S2	X		X	X	X	X	X
32	Pipe Fail Potential given Ground Movement	GndFailPot		S2	X		X	X	X	X	X
33	Depth Range (calculated from elevation/depth profile)	DepthRange		S2	X	X	X	X	X	X	X
34	Adjacent Platform Type	PlatType		P1a		X	X	X	X	X	X
	Adjacent Platform Offset	PlatOffset	m	P1b							
35	Spill Trajectory Launch Zones	LaunchZone		S3		X		X		X	X
36	Susceptible Coastal Resources	Resource		P2a		X		X		X	X
	Coastal Resource Shoreline Types	ShoreType		P2b							
37	Coastal Resource Impact Probability	ImpactLoc		P3		X		X		X	X
38	Coastal Resource Impact Time	ImpactTime		P4		X		X		X	X

Attribute Data Input Type

S1 all consecutive sections delineated by KP start & KP end, defined by numeric value
S2 all consecutive sections delineated by KP start & KP end, defined by text string from predefined choice list
S3 all consecutive sections delineated by KP start & KP end, defined by an index value associated with a user defined text string
C1 continuously varying quantity defined by numeric values at KP reference locations
P1 selected locations defined by: a) an index value associated with a text string from a predefined choice list and b) a numeric value
P2 selected locations defined by: a) an index value associated with a user defined text string and b) an index value associated with a text string from a predefined choice list
P3 all user defined locations defined by a numeric value
P4 all user defined locations defined by a probability distribution

Table 2.5 Line attributes required for prioritization of offshore pipelines

No.	Attribute Description	Input Type	S1			S2	S3	S4	S5
			S1-1	S1-2	S1-3				
1	Pipe Diameter (mm)	S1	237	237	237	237	237	237	237
2	Pipe Wall Thickness (mm)	S1	15.09	15.09	15.09	15.09	15.09	15.09	15.09
3	Pipe Body Yield Strength (MPa)	S1	241	241	241	241	241	241	241
4	Pipe Joint Type	S2	High Quality Weld	High Quality Weld	High Quality Weld	High Quality Weld	High Quality Weld	High Quality Weld	High Quality Weld
5	Line Age (years)	S1	1	1	1	1	25	1	25
6	Pipe Orientation (deg)	S1	0	0	0	0	0	0	0
7	Line Elevation/Depth Profile (m)	C1	-12.3525	-15.25	-18.1475	-15.3	-15.3	-15.25	-15.3
8	Operating Pressure Profile (kPa)	C1	8254.78	7927.5	7600.23	7930	7930	7930	7930
9	Longitudinal Stress Range (MPa)	S1	1.00E-07	1.00E-07	1.00E-07	1.00E-07	1.00E-07	1.00E-07	1.00E-07
10	Cumulative No. of Longitudinal Stress Cycles	S1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
11	No. of Pipe Free Spans (/km)	S1	0	0	0	0	0	0	0
12	Operating Temperature (°C)	S1	21	21	21	21	21	21	21
13	Product Flow Rate (kg)	S1	15	15	15	15	15	15	15
14	Line Volume (percentage of line capacity)	S1	100	100	100	100	100	100	100
15	Billing Abatement Threshold (percentage of nominated volume)	S1	100	100	100	100	100	100	100
16	Product Transport. Distance (km)	S1	20	20	20	20	20	20	20
17	Block Valve Spacing (km)	S1	20	20	20	20	20	20	20
18	Time to Block Valve Spacing (min)	S1	30	30	30	30	30	30	30
19	Detectable Release Volume (cu.m.)	S1	200	200	200	200	200	200	200
20	Time to Leak Detection (hrs)	S1	24	24	24	1	24	24	1
21	Time to Leak Stoppage - from time of detection (hrs)	S1	24	24	24	24	24	24	24
22	Depth of cover	S2	Continuous, Significant Coverage	Continuous, Significant Coverage	Continuous, Significant Coverage	Continuous, Significant Coverage	Intermittent or Partial Coverage	Continuous, Significant Coverage	Intermittent or Partial Coverage
23	Vessel Traffic Density	S2	Moderate Traffic Density	Moderate Traffic Density	Moderate Traffic Density	Moderate Traffic Density	High Traffic Density	Low Traffic Density	Moderate Traffic Density
24	Subsea Activity	S2	No	No	No	Yes	No	No	Yes
25	Seabed Environment Corrosivity	S2	Very Low	Very Low	Very Low	Very Low	Moderate	Very Low	Moderate
26	SCC Potential of Soil Environment	S2	No Potential	No Potential	No Potential	No Potential	No Potential	No Potential	No Potential
27	External Pipe Coating Type	S2	Poly/Epoxy	Poly/Epoxy	Poly/Epoxy	Poly/Epoxy	Poly/Epoxy	Poly/Epoxy	Poly/Epoxy
28	External Pipe Coating Condition	S2	Above Average	Above Average	Above Average	Above Average	Below Average	Above Average	Below Average
29	Cathodic Protection Level	S2	Above Average	Above Average	Above Average	Above Average	Below Average	Above Average	Below Average
30	Product Corrosivity	S2	Negligible (<0.02 mm/yr)	Negligible (<0.02 mm/yr)	Negligible (<0.02 mm/yr)	Negligible (<0.02 mm/yr)	Low (0.02-0.1 mm/yr)	Negligible (<0.02 mm/yr)	Low (0.02-0.1 mm/yr)
31	Ground Movement Potential	S2	Negligible (<= 1 in 100k /km)	Negligible (<= 1 in 100k /km)	Negligible (<= 1 in 100k /km)	Negligible (<= 1 in 100k /km)	Negligible (<= 1 in 100k /km)	Negligible (<= 1 in 100k /km)	Negligible (<= 1 in 100k /km)
32	Pipe Fail Potential given Ground Movement	S2	Low (<= 1 in 100)	Low (<= 1 in 100)	Low (<= 1 in 100)	Low (<= 1 in 100)	Low (<= 1 in 100)	Low (<= 1 in 100)	Low (<= 1 in 100)
33	Depth Range - calculated from elevation/depth profile	S2	Deep (10 to < 60 m)	Deep (10 to < 60 m)	Deep (10 to < 60 m)	Deep (10 to < 60 m)	Deep (10 to < 60 m)	Deep (10 to < 60 m)	Deep (10 to < 60 m)
34	Adjacent Platform Type	P1a	Minor Unmanned	None	Major Manned	Major Manned	None	None	Major Unmanned
	Adjacent Platform Offset (m)	P1b	0	N/A	0	0	N/A	N/A	0
35	Spill Trajectory Launch Zones	S3	N/A	N/A	N/A	N/A	N/A	N/A	N/A
36	Susceptible Coastal Resources	P2a	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Coastal Resource Shoreline Types	P2b	N/A	N/A	N/A	N/A	N/A	N/A	N/A
37	Coastal Resource Impact Probability	P3	N/A	N/A	N/A	N/A	N/A	N/A	N/A
38	Coastal Resource Impact Time	P4	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Attribute Data Input Type

S1 all consecutive sections delineated by KP start & KP end, defined by numeric value

S2 all consecutive sections delineated by KP start & KP end, defined by text string from predefined choice list

S3 all consecutive sections delineated by KP start & KP end, defined by an index value associated with a user defined text string

C1 continuously varying quantity defined by numeric values at KP reference locations

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P2 selected locations defined by: a) an index value associated with a user defined text string and b) an index value associated with a text string from a predefined choice list

P3 all user defined locations defined by a numeric value

P4 all user defined locations defined by a probability distribution

Table 2.6 Line attributes for offshore pipeline sections analysed.

3. RESULTS OF ANALYSIS

3.1 Risk Measures Considered

For each attribute-consistent section of pipeline, the *PIRAMID*™ Prioritization programs provide estimates of the operating risk posed by each significant potential failure mechanism. These risk estimates can be displayed on a cause-by-cause basis, or for all causes combined. For gas pipelines, the specific risk measures tabulated include:

- *Probability of Failure.* An estimate of the expected number of loss-of-containment incidents (in units of: incidents per km yr, or incidents per mi yr).
- *Expected Cost.* A probability weighted estimate of the financial cost associated with failure incidents (in units of: $ per km yr, or $ per mi yr).
- *Expected Number of Fatalities.* A probability weighted estimate of the total number of fatalities associated with failure incidents (in units of: people per km yr, or people per mi yr).
- *Total Risk.* A probability weighted estimate of the total effective cost associated with failure incidents, where the effective cost includes the assumed dollar cost equivalent of lives lost (in units of: $ per km yr, or $ per mi yr).

The results presented in this study are for the most part restricted to include only the estimates of *Total Risk* and *Probability of Failure*. *Expected Cost* and *Expected Number of Fatalities* are not discussed separately since they are reflected, in a combined sense, in the *Total Risk* estimate. The *Probability of Failure* estimates are analysed separately, even though they are reflected in the *Total Risk* estimate, because they allow for direct assessment of the probability estimation models incorporated in the prioritization program.

3.2 On shore Pipelines

The all-causes-combined risk measures estimated to apply to each line section are reported in Table 3.1. In the tabulated summary, line sections have been sorted by Total Risk and ordered from maximum to minimum. The tabulation, therefore, constitutes a ranking of the line sections analysed with the section estimated to have the highest level of operating risk (due to all-causes-combined) appearing at the top of the list.

A graphical representation of the operating risk estimated for each section is shown in Figure 3.1. The purpose of Figure 3.1, with the vertical chart axis (*i.e.*, the Total Risk axis) plotted using an arithmetic scale, is to illustrate the extreme range of risk estimates obtained using the program. A similar chart, with Total Risk plotted using a logarithmic scale is shown in Figure 3.2. (Note that all subsequent plots of this type incorporate a logarithmic scale for clarity.)

Results of Analysis

The individual line sections plotted in Figure 3.2 are also labelled to indicate associated land use type (using a 'text string') and diameter range (using a letter code: S = small, and L = large). Note the apparent lack of correlation between line diameter and risk level, and the obvious correlation between risk level and land use type with high risk sections almost always being associated with high density urban land use. (The sole exception to the latter trend being line section D4, where the relatively high risk ranking is attributed to an extremely high estimate of the probability of line failure.)

Also plotted in Figure 3.2 are the Probability of Failure estimates for each line section and, for comparison purposes, the baseline reference failure rate that is assumed to be applicable to typical transmission-type gas pipelines. Note that on average, the total failure probability estimate is higher for the small diameter (relatively thin-walled) lines.

Figures 3.3 and 3.4 present subsets of the data shown in Figure 3.2, with Figure 3.3 showing Total Risk and Failure Probability estimates for small diameter lines only and Figure 3.4 showing similar information for large diameter lines. These charts are further annotated with a letter code indicating both perceived likelihood of failure and severity of failure consequences (first letter for probability and second letter for consequences, where: L = low, M = medium, and H = high). Note that sections for which the perceived probability level is not entirely consistent with the probability estimate obtained using the prioritization model are labelled accordingly (identifying label = ?). Note also that these apparent inconsistencies form the basis for some of the comments and suggestions for model improvements outlined in Section 4.0.

Figures 3.5 and 3.6, corresponding to Figures 3.3 and 3.4 respectively, show the relative contributions of each of the individual failure mechanisms to the Total Risk estimate. Note the significant contribution of mechanical damage failures to the Total Risk estimate for small diameter (relatively thin walled) line sections, particularly those in urban areas, and the comparatively small contribution of mechanical damage to the total Risk for large diameter line sections. Note also the significant contribution to Total Risk from SCC on both small and large diameter lines which were specified as having a soil environment with a likely or definite potential for fostering the occurrence of SCC. Finally, note the dominance of 'other causes' on selected large diameter lines where failure due to the remaining failure mechanisms is estimated to be low (the dominance of 'other causes' reflects the fact that the failure probability due to this cause is assumed to be constant).

Tabulations of the Total Risk estimates and the Probability of Failure estimates, for each individual failure cause and for all-causes-combined, are given respectively in Tables 3.2 and 3.3 for small diameter line sections and Tables 3.4 and 3.5 for large diameter line sections.

A ranking of line sections by Total Risk, on a cause-by-cause basis, is given in Table 3.6. It is intended that this type of cause-specific risk ranking will serve as the basis for maintenance prioritization and it is the default format for the display of output generated by the *PIRAMID*™ prioritization programs. A graphical representation of the cause-specific risk ranking, excluding the "other causes" category (since it is assumed that no specific maintenance action is effective for this cause), is shown in Figure 3.7, for small diameter line sections, and Figure 3.8 for the

large diameter lines. Note that the risk ranking keys on the dominant failure mechanisms for each of the high risk segments, most notably mechanical damage for small diameter lines in urban areas.

3.3 Offshore Pipelines

The all-causes-combined risk measures estimated to apply to each line section are reported in Table 3.7. The tabulated summary has been sorted by Total Risk and ordered from maximum to minimum. The tabulation, therefore, constitutes a ranking of the line sections analyses with the section estimated to have the highest level of operating risk (due to all-causes-combined) appearing at the top of the list.

A graphical representation of the operating risk estimated for each section is shown in Figure 3.9. Note the extreme range of risk estimates obtained using the program. A similar chart, with Total Risk plotted using a logarithmic scale for clarity, is shown in Figure 3.10.

The individual line sections plotted in Figure 3.10 are labelled to indicate relative line age and proximity to fixed offshore structures or surface vessel traffic. Note that since line section S1 is actually a composite of three distinct attribute-consistent line sections, its proximity label is given as 'mixed'. In addition, the charts are annotated with a letter code indicating both perceived likelihood of failure and severity of failure consequences (first letter for probability and second letter for consequences, where: L = low, M = medium, and H = high). Also plotted in Figure 3.10 are the Probability of Failure estimates for each line section and, for comparison purposes, the baseline reference failure rate that is assumed to be applicable to typical offshore gas pipelines. Note the correlations between Probability of Failure and line age (higher probability for older lines), and between Total Risk and proximity to platforms (higher risk for lines near platforms).

Figure 3.11 shows the relative contributions of each of the individual failure mechanisms to the Total Risk estimate for the lines section plotted in Figure 3.10. Note the dominating contribution of mechanical damage and natural hazard failures to the Total Risk estimate for line sections in proximity to platforms (the natural hazard damage category is significant because it includes storm-induced mechanical damage). Note also the dominance of "other causes" on line sections removed from platform zones, or with minimal platform zone exposure, where failure due to the remaining failure mechanisms is estimated to be low (the low product corrosivity and the choice of a high performance coating type result in a low corrosion failure potential, and the relatively isolated location results in a low mechanical damage potential).

Tabulations of the Total Risk estimates and the Probability of Failure estimates, for each individual failure cause and for all-causes-combined, are given in Tables 3.8 and 3.9, respectively.

A ranking of line sections by Total Risk, on a cause-by-cause basis, is given in Table 3.10. As noted for onshore pipelines, it is intended that this type of cause-specific risk ranking will serve

as the basis for maintenance prioritization and it is the default format for the display of output generated by the prioritization program.

A graphical representation of the cause-specific risk ranking, excluding the "other causes" category (since it is assumed that no specific maintenance action is effective for this cause), is shown in Figure 3.12. Note that the risk ranking keys on the dominant failure mechanisms for each of the high risk segments, most notably mechanical damage and natural hazard induced damage for lines in proximity to platforms.

Figures and Tables

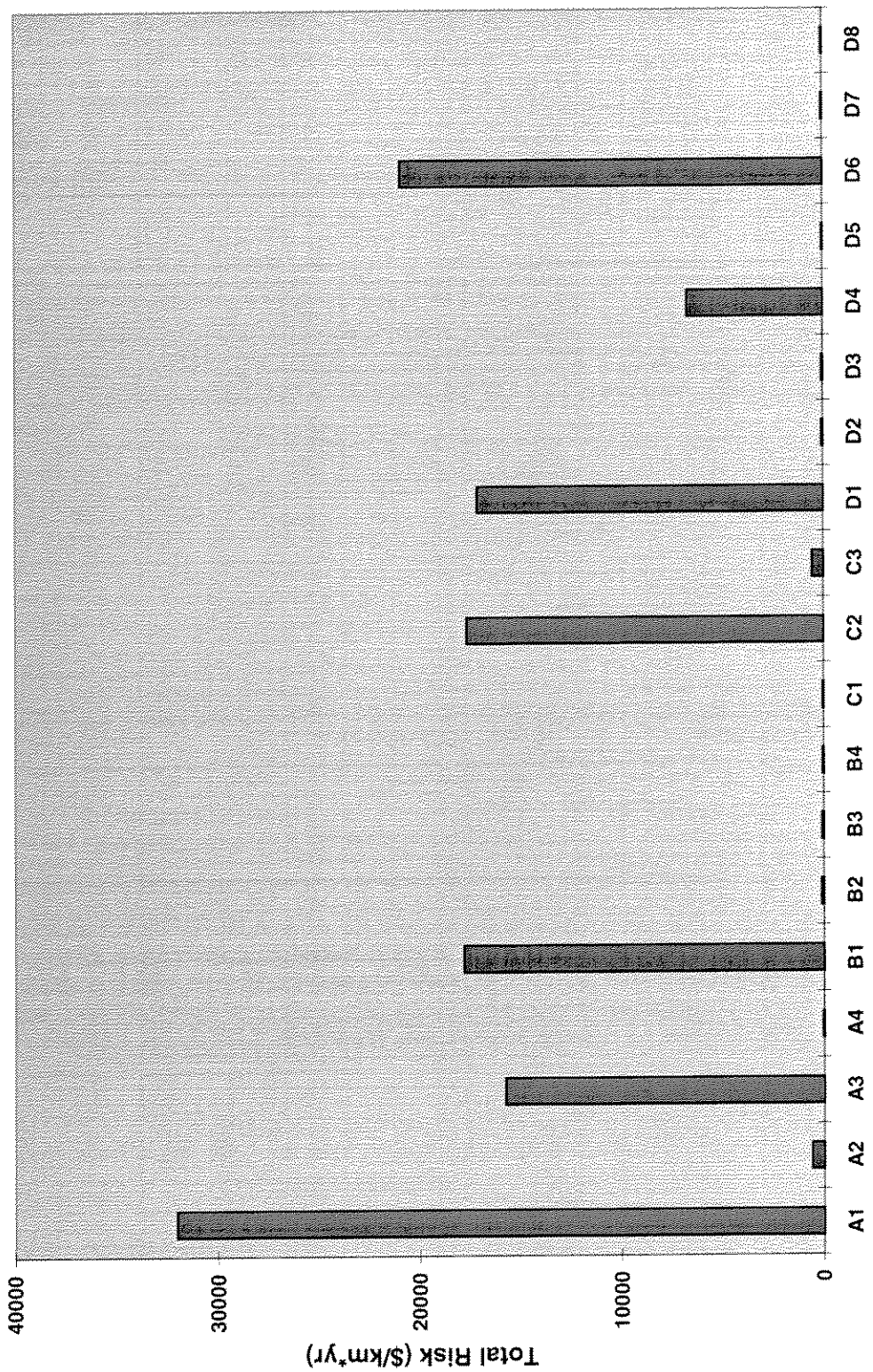


Figure 3.1 Total risk estimates for onshore pipelines.

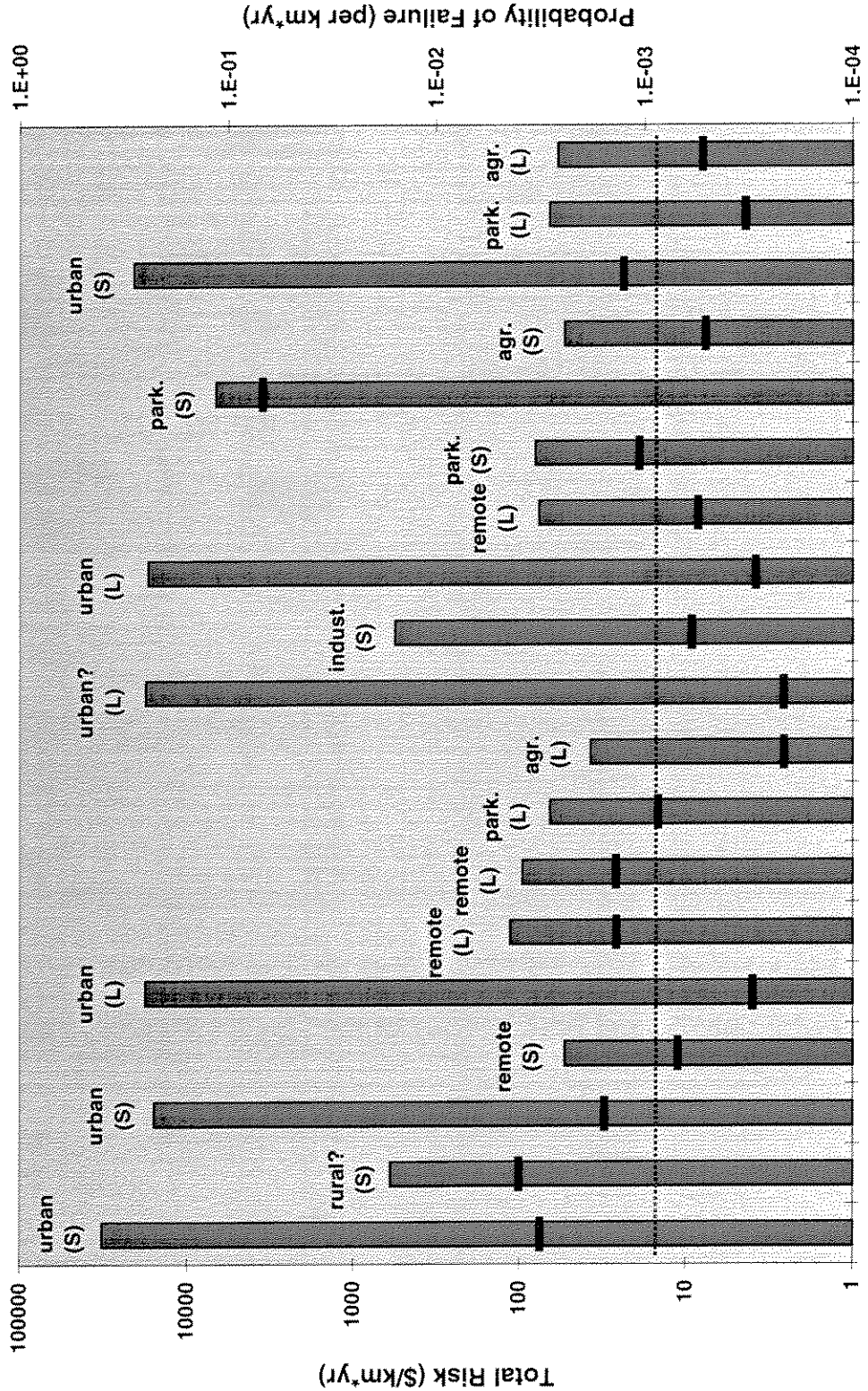


Figure 3.2 Total risk and failure probability estimates for onshore pipelines.

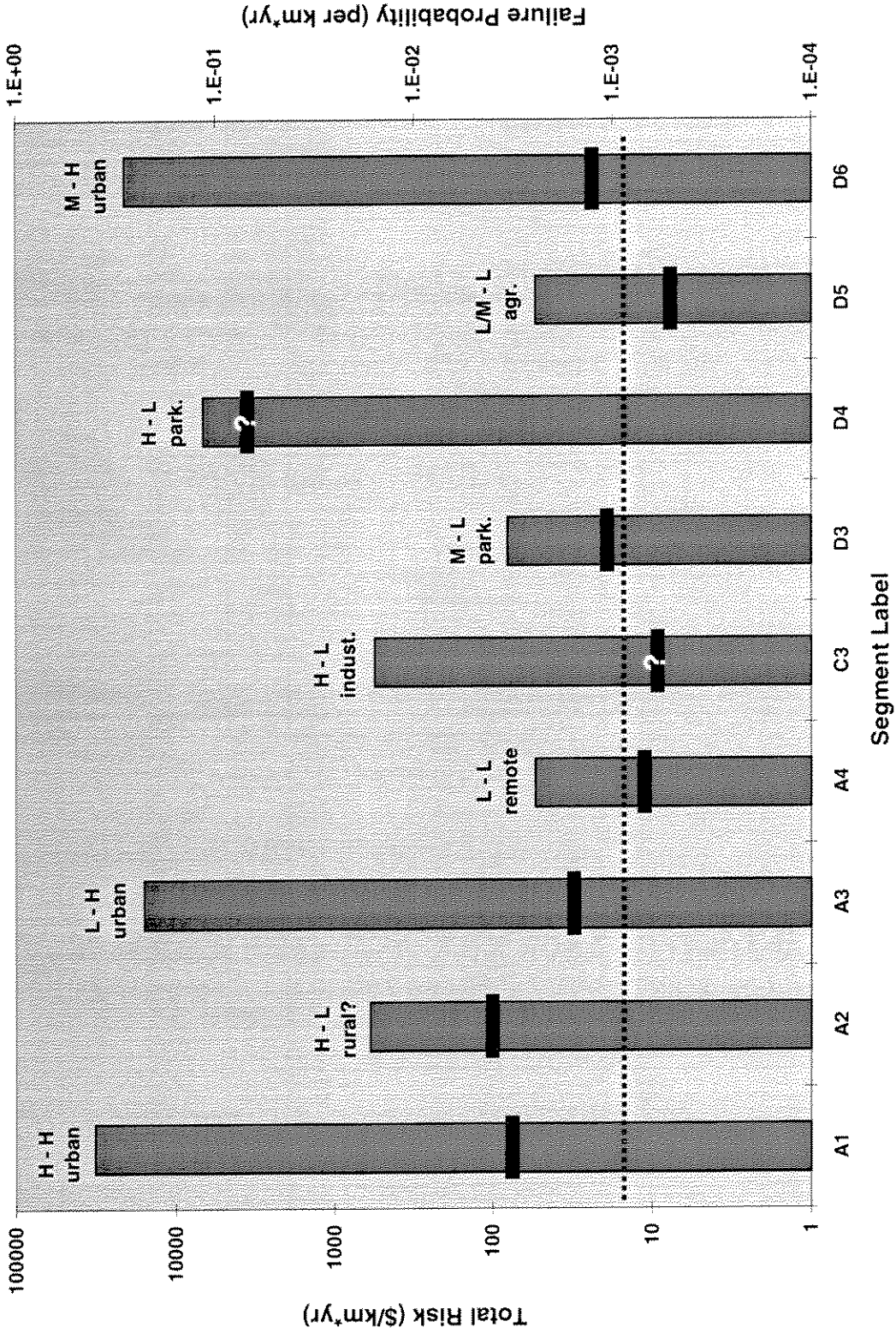


Figure 3.3 Total risk and failure probability estimates for small diameter onshore pipelines.

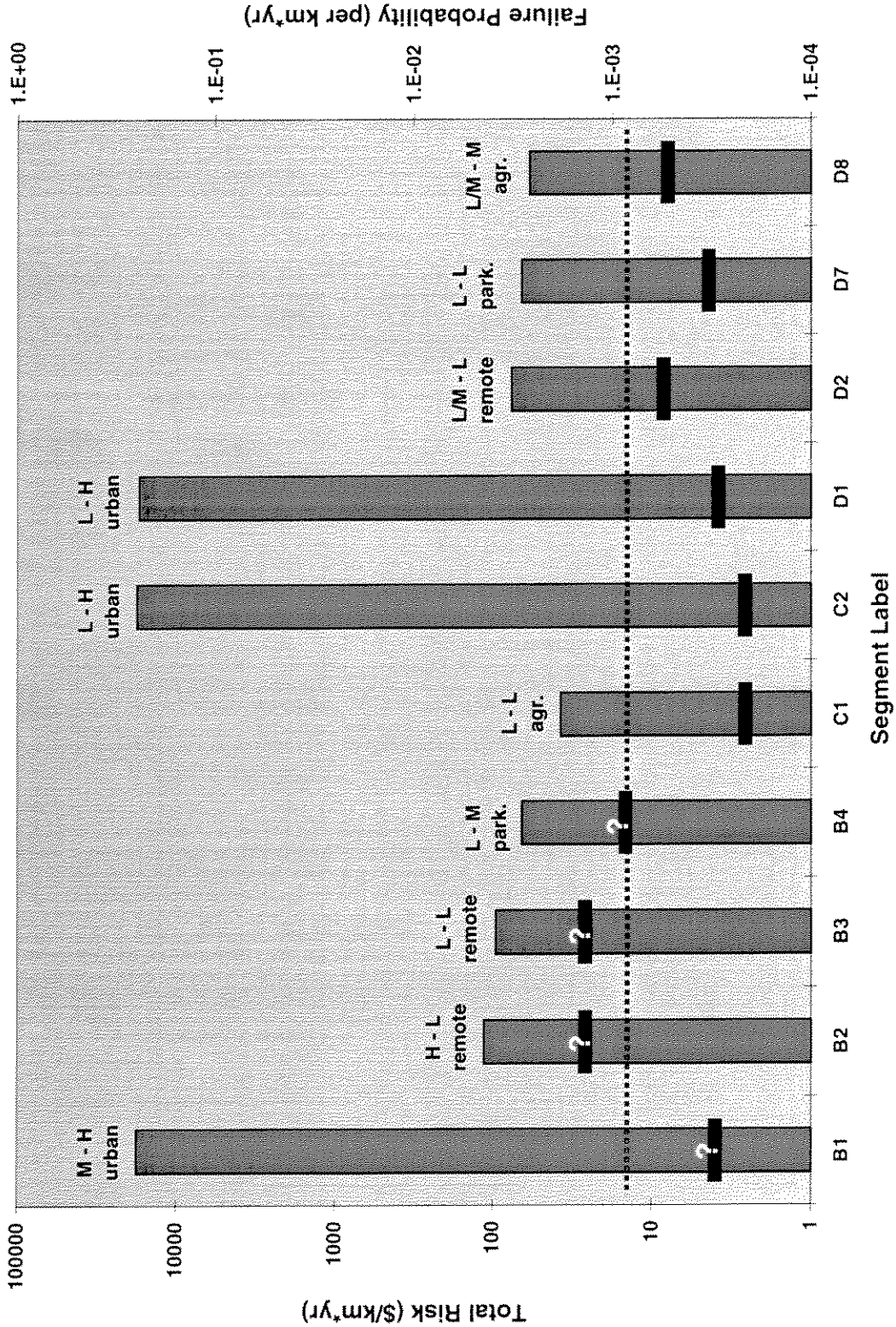


Figure 3.4 Total risk and failure probability estimates for large diameter onshore pipelines.

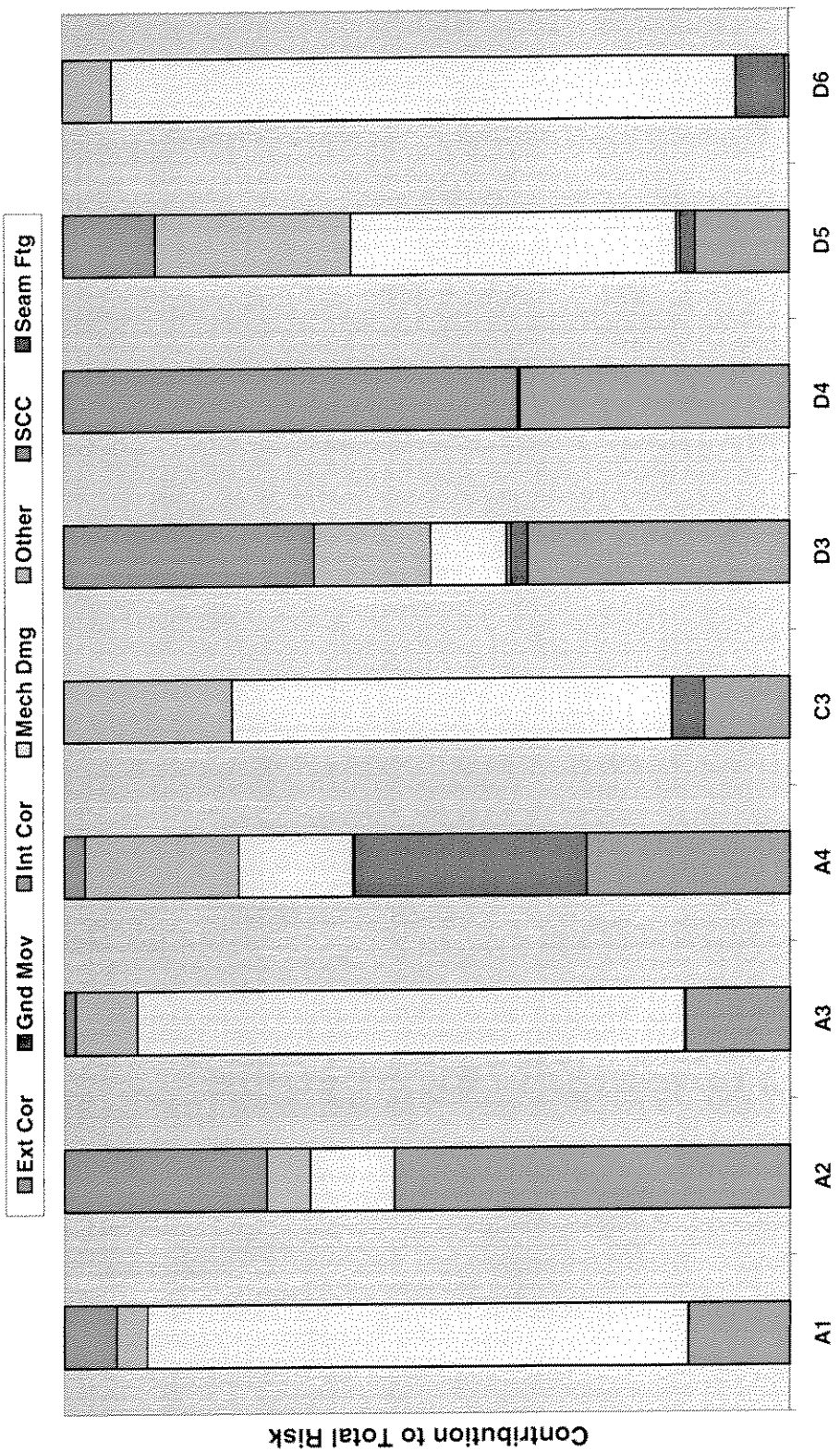


Figure 3.5 Relative contributions of individual failure causes to total risk for small diameter onshore pipelines.

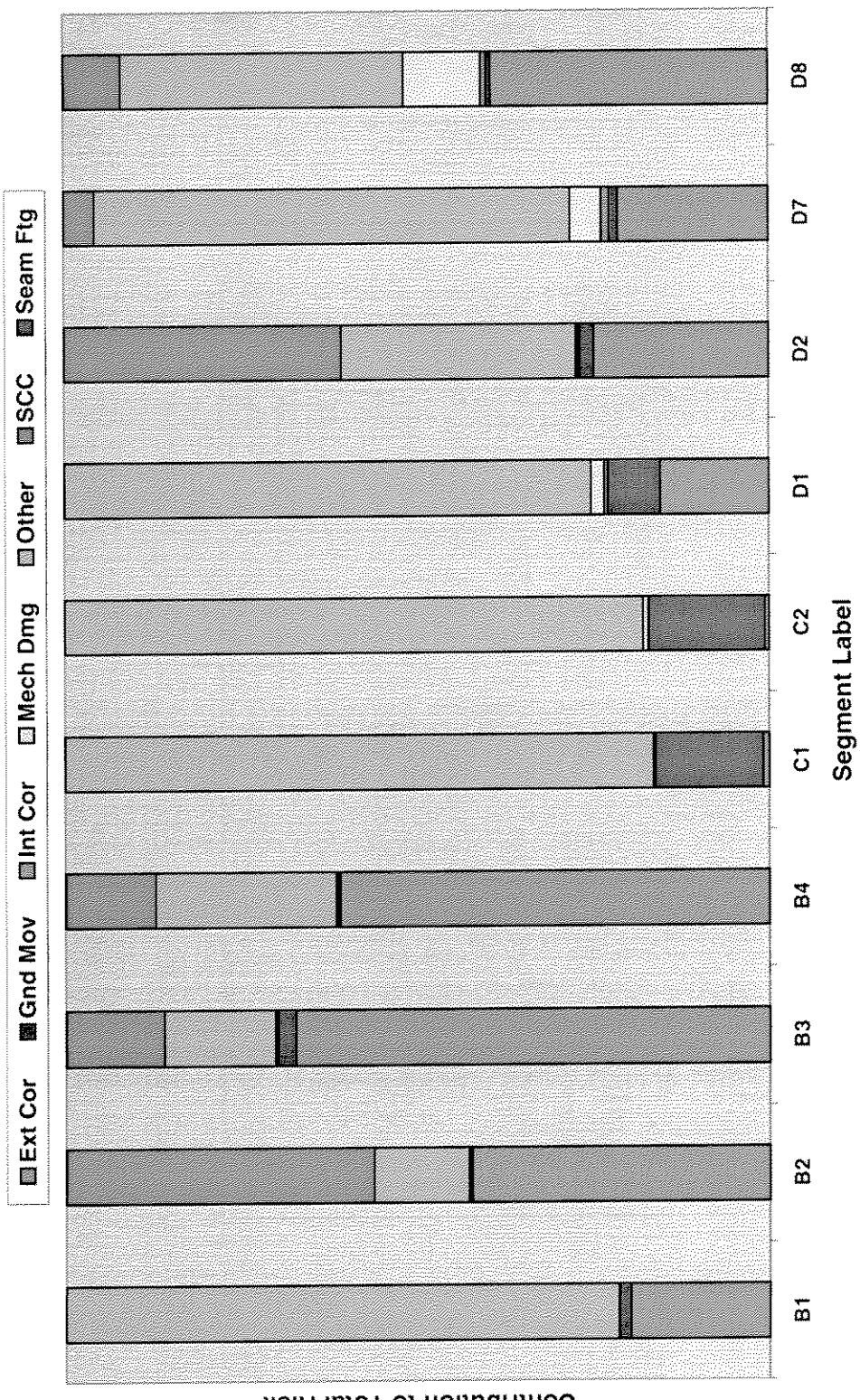


Figure 3.6 Relative contributions of individual failure causes to total risk for large diameter onshore pipelines.

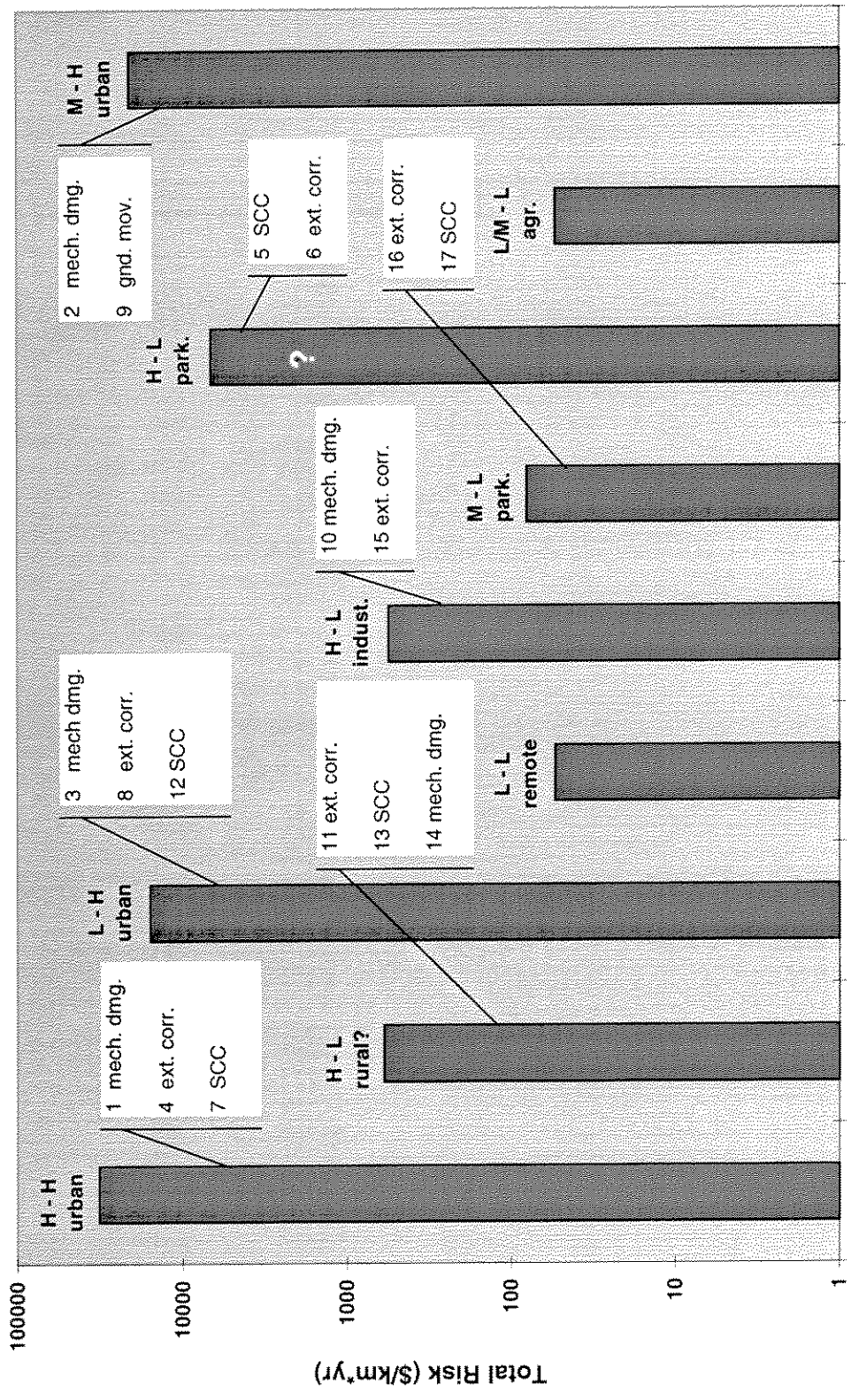


Figure 3.7 Risk ranking of small diameter onshore pipelines (by failure cause).

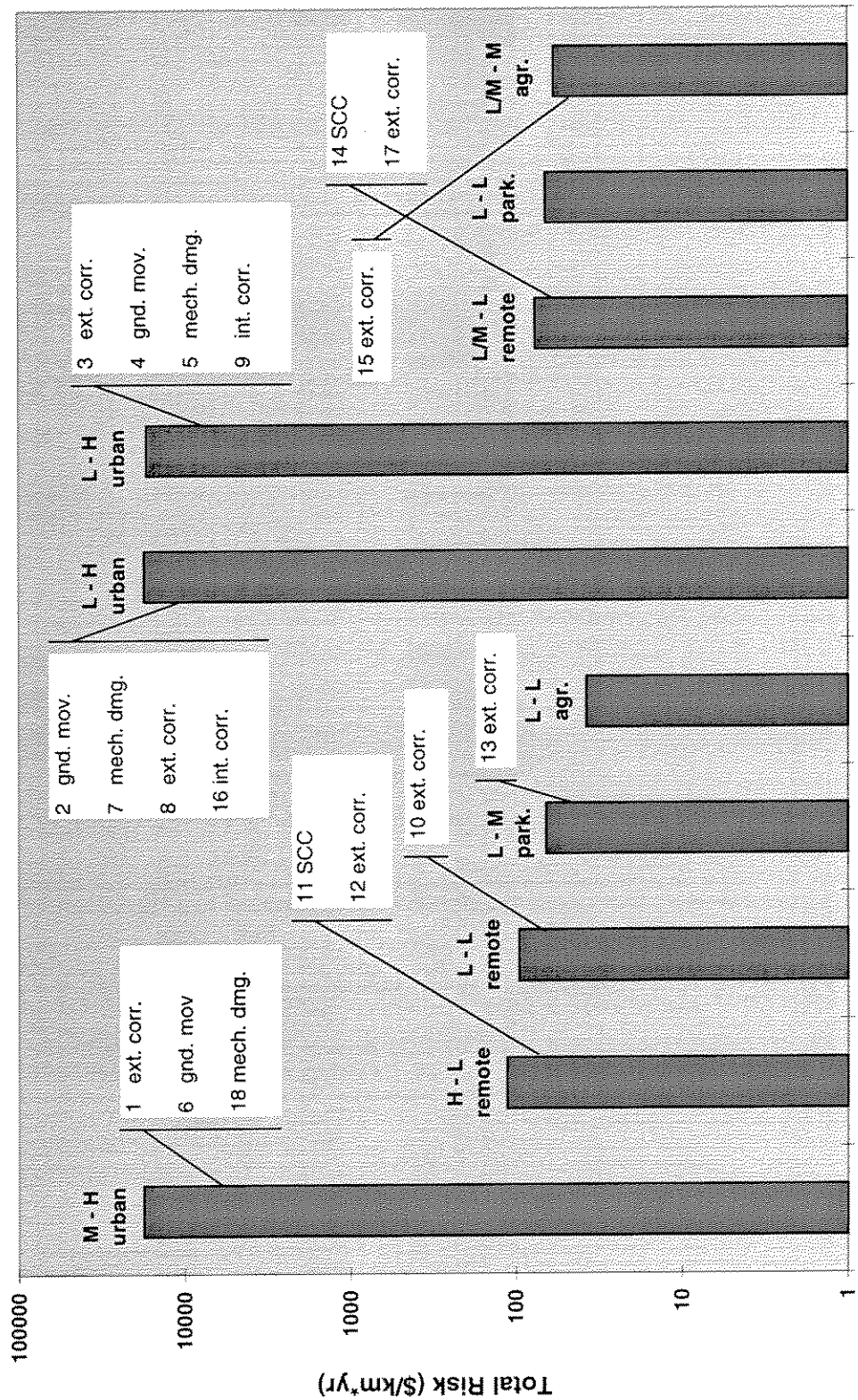


Figure 3.8 Risk ranking of large diameter onshore pipelines (by failure cause).

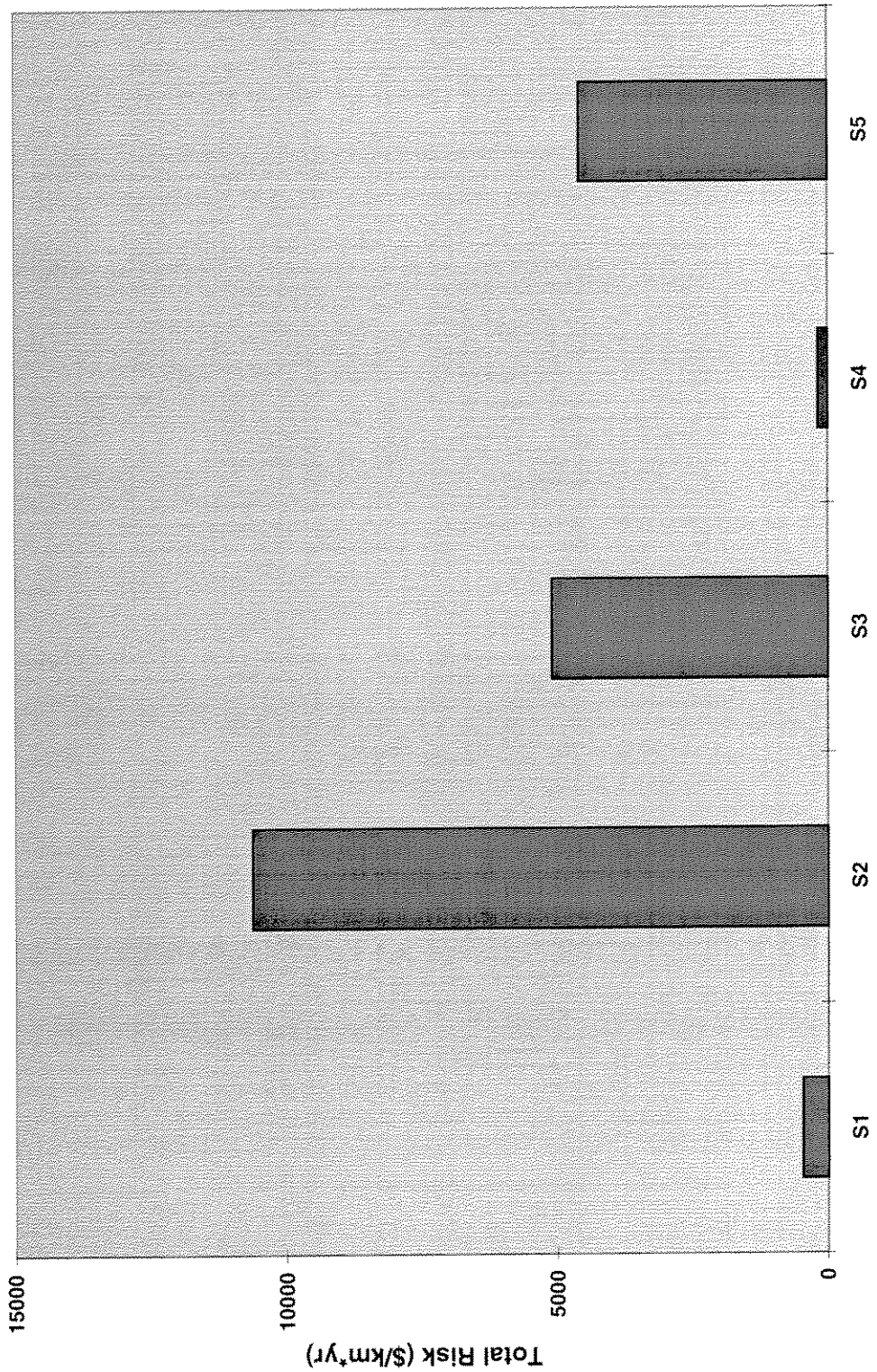


Figure 3.9 Total risk estimates for offshore pipelines.

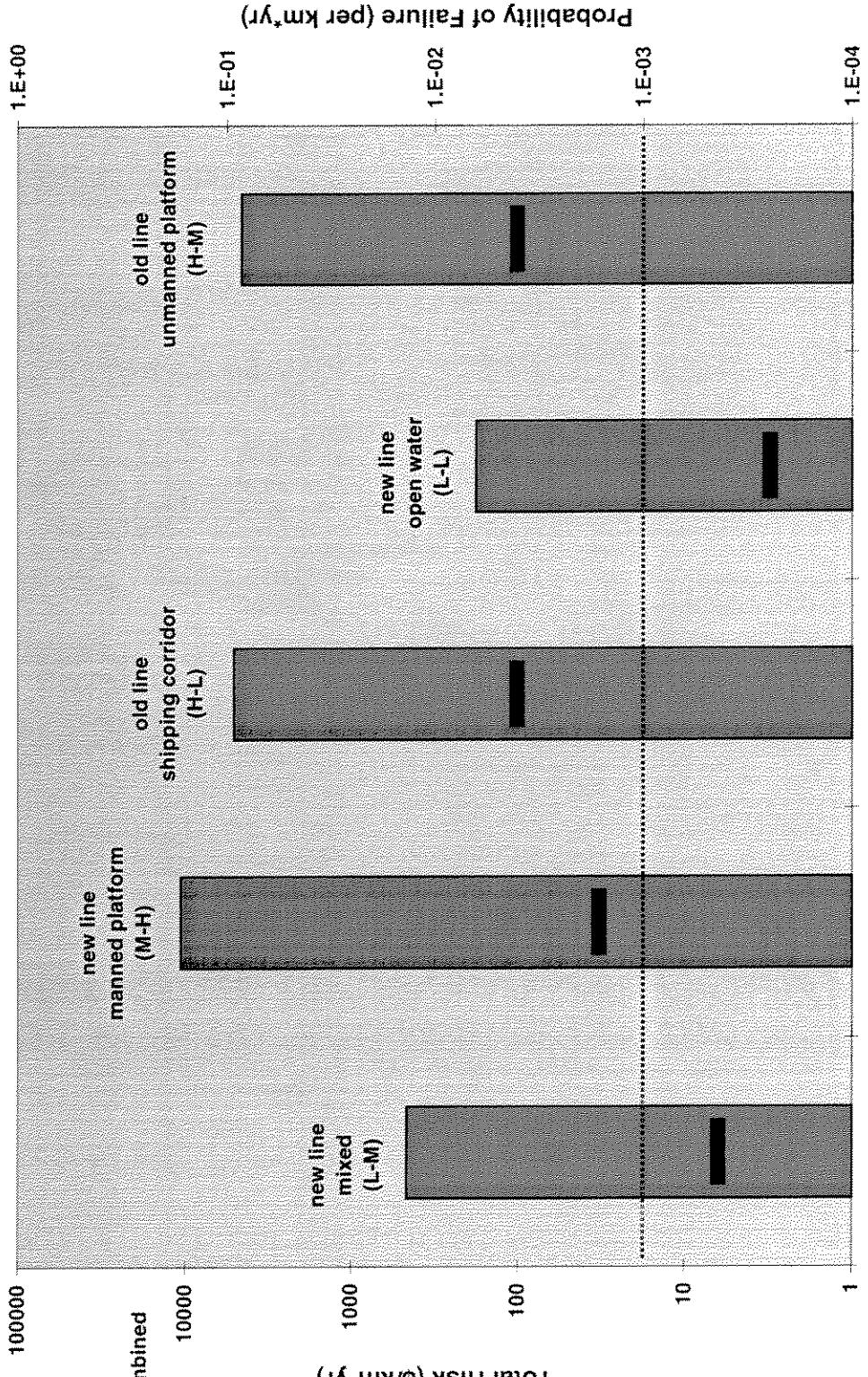


Figure 3.10 Total risk and failure probability estimates for offshore pipelines.

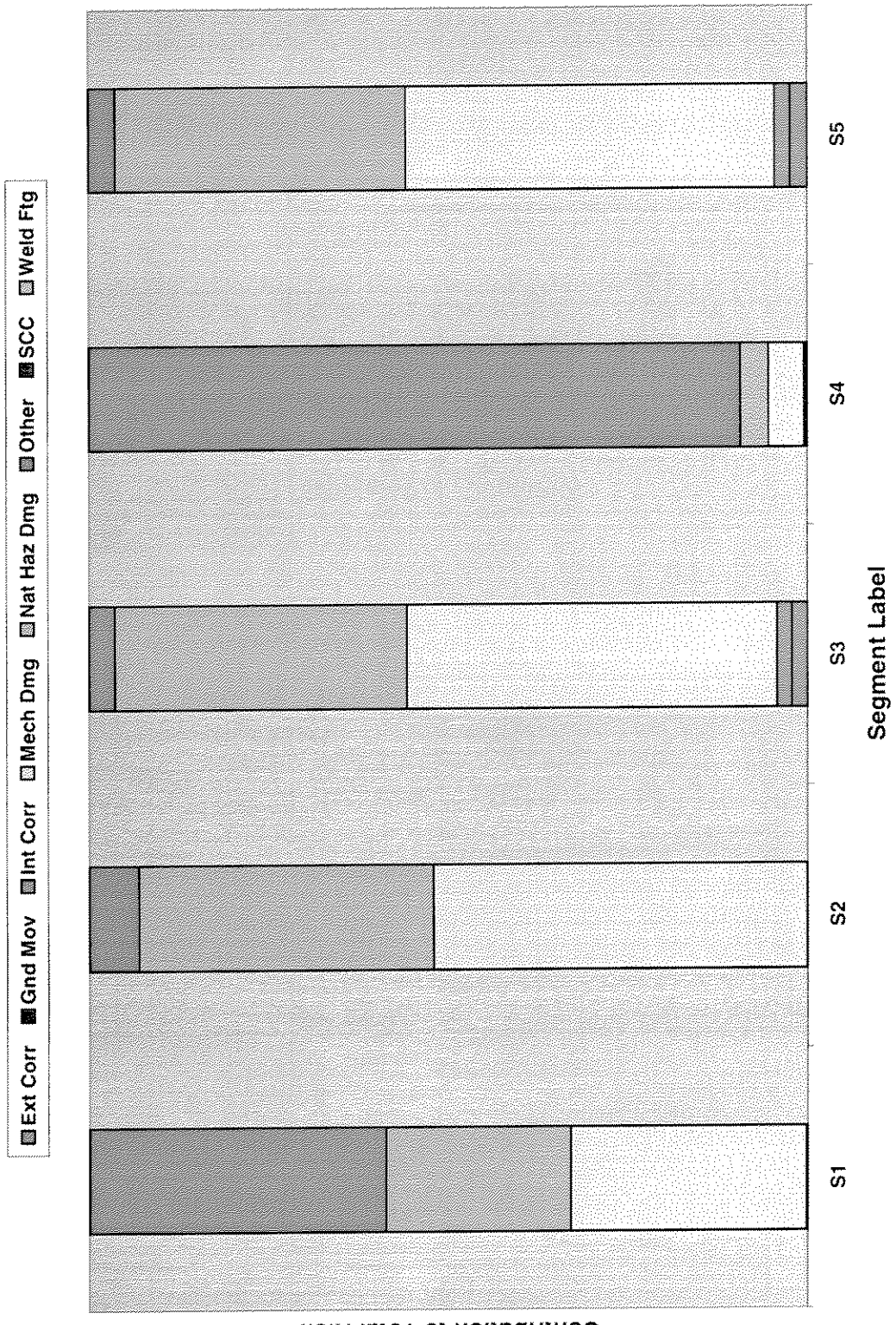


Figure 3.11 Relative contributions of individual failure causes to total risk for offshore pipelines.

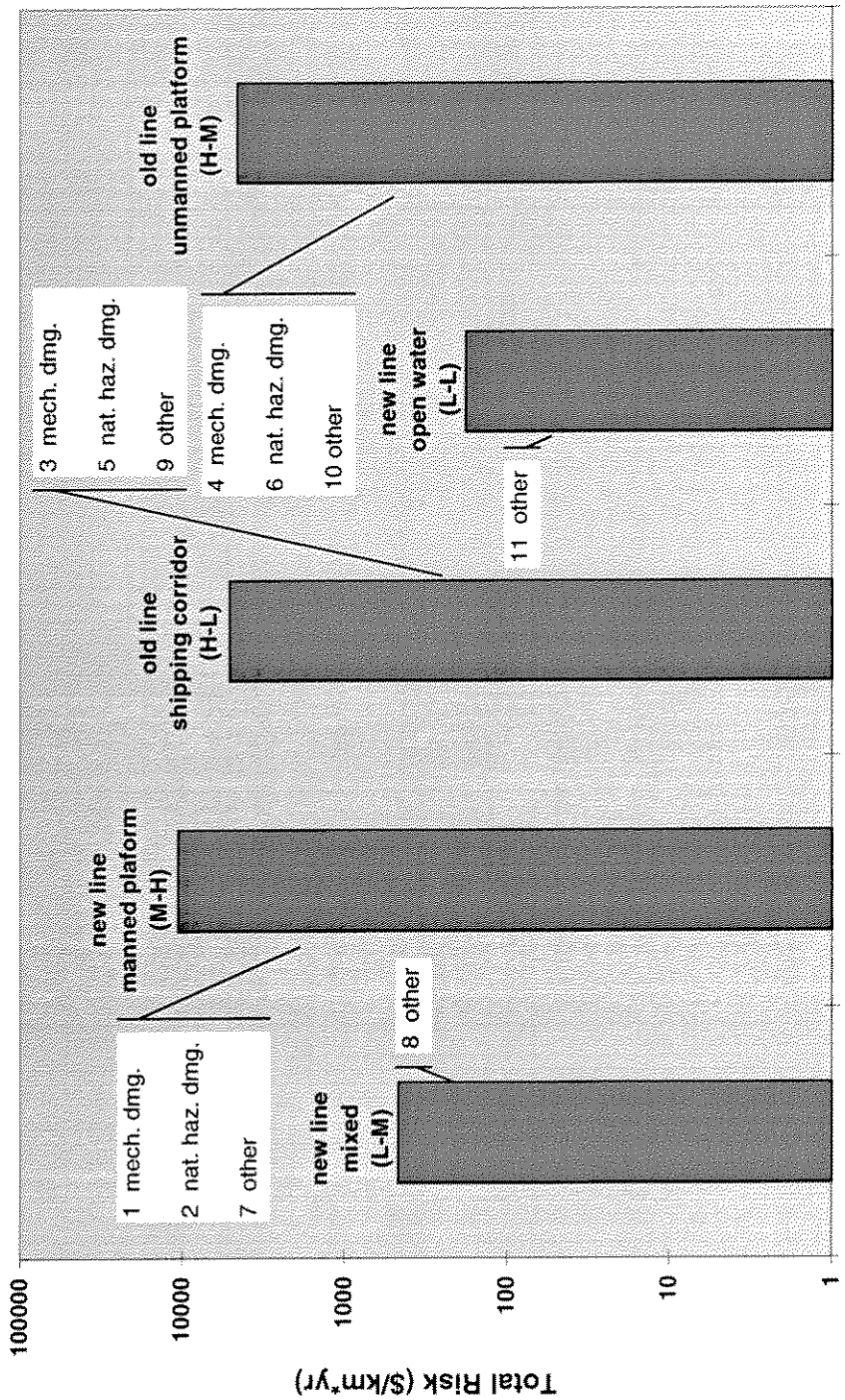


Figure 3.12 Risk ranking of offshore pipelines (by failure cause).

Rank	Segment	Total Risk ($/km yr)	Prob. Fail (per km yr)	Exp. Cost ($/km yr)	Exp. Fatal. (per km yr)
1	A1	3.20E+04	3.18E-03	1.07E+04	1.07E-02
2	D6	2.09E+04	1.27E-03	6.98E+03	6.97E-03
3	B1	1.78E+04	3.01E-04	5.83E+03	5.98E-03
4	C2	1.76E+04	2.14E-04	5.79E+03	5.93E-03
5	D1	1.71E+04	2.91E-04	5.61E+03	5.75E-03
6	A3	1.58E+04	1.56E-03	5.31E+03	5.22E-03
7	D4	6.71E+03	6.87E-02	6.71E+03	0.00E+00
8	A2	5.96E+02	4.01E-03	3.91E+02	1.03E-04
9	C3	5.60E+02	5.91E-04	4.06E+02	7.67E-05
10	B2	1.14E+02	1.37E-03	1.14E+02	0.00E+00
11	B3	9.60E+01	1.38E-03	9.60E+01	0.00E+00
12	D3	8.05E+01	1.06E-03	8.05E+01	0.00E+00
13	D2	7.64E+01	5.53E-04	7.64E+01	0.00E+00
14	D7	6.60E+01	3.27E-04	6.60E+01	0.00E+00
15	B4	6.58E+01	8.59E-04	6.58E+01	0.00E+00
16	D8	5.88E+01	5.27E-04	5.03E+01	4.26E-06
17	A4	5.39E+01	6.89E-04	5.39E+01	0.00E+00
18	D5	5.38E+01	5.08E-04	5.12E+01	1.29E-06
19	C1	3.77E+01	2.13E-04	3.40E+01	1.83E-06

Table 3.1 Risk estimates for onshore pipelines (all causes combined).

Rank	Segment	Total Risk ($/km yr) Combined	Total Risk ($/km yr) Ext Cor	Total Risk ($/km yr) Gnd Mov	Total Risk ($/km yr) Int Cor	Total Risk ($/km yr) Mech Dmg	Total Risk ($/km yr) Other	Total Risk ($/km yr) SCC	Total Risk ($/km yr) Seam Ftg
1	A1	3.20E+04	4.48E+03	2.64E+00	8.56E+00	2.39E+04	1.34E+03	2.30E+03	0.00E+00
8	A2	5.96E+02	3.25E+02	6.56E-02	2.70E-01	6.91E+01	3.57E+01	1.66E+02	0.00E+00
6	A3	1.58E+04	2.26E+03	2.65E+01	8.60E+00	1.19E+04	1.34E+03	2.32E+02	0.00E+00
17	A4	5.39E+01	1.51E+01	1.72E+01	1.15E-01	8.49E+00	1.14E+01	1.53E+00	0.00E+00
9	C3	5.60E+02	6.52E+01	2.52E+01	4.02E-01	3.40E+02	1.29E+02	0.00E+00	0.00E+00
12	D3	8.05E+01	2.90E+01	1.85E+00	5.09E-01	8.38E+00	1.30E+01	2.77E+01	0.00E+00
7	D4	6.71E+03	2.49E+03	2.06E+00	5.26E-01	5.16E+00	1.67E+01	4.19E+03	0.00E+00
18	D5	5.38E+01	6.90E+00	1.10E+00	3.14E-01	2.42E+01	1.45E+01	6.79E+00	0.00E+00
2	D6	2.09E+04	1.21E+02	1.38E+03	1.30E+01	1.80E+04	1.40E+03	0.00E+00	0.00E+00

Table 3.2 Total risk estimates for small diameter onshore pipelines (by failure cause).

Rank	Segment	Prob. Fail (per km yr) Combined	Prob. Fail (per km yr) Ext Cor	Prob. Fail (per km yr) Gnd Mov	Prob. Fail (per km yr) Int Cor	Prob. Fail (per km yr) Mech Dmg	Prob. Fail (per km yr) Other	Prob. Fail (per km yr) SCC	Prob. Fail (per km yr) Seam Ftg
1	A1	3.18E-03	1.27E-03	1.00E-07	2.43E-06	1.39E-03	2.00E-04	3.18E-04	0.00E+00
8	A2	4.01E-03	2.93E-03	1.00E-07	2.43E-06	1.45E-04	2.00E-04	7.32E-04	0.00E+00
6	A3	1.56E-03	6.40E-04	1.00E-06	2.43E-06	6.87E-04	2.00E-04	3.20E-05	0.00E+00
17	A4	6.89E-04	3.18E-04	1.00E-04	2.43E-06	5.20E-05	2.00E-04	1.59E-05	0.00E+00
9	C3	5.91E-04	1.81E-04	1.00E-05	1.11E-06	1.99E-04	2.00E-04	0.00E+00	0.00E+00
12	D3	1.06E-03	5.30E-04	1.00E-05	9.28E-06	4.80E-05	2.00E-04	2.65E-04	0.00E+00
7	D4	6.87E-02	3.42E-02	1.00E-05	7.23E-06	2.67E-05	2.00E-04	3.42E-02	0.00E+00
18	D5	5.08E-04	1.18E-04	5.00E-06	5.36E-06	1.21E-04	2.00E-04	5.90E-05	0.00E+00
2	D6	1.27E-03	3.21E-05	5.00E-05	3.45E-06	9.83E-04	2.00E-04	0.00E+00	0.00E+00

Table 3.3 Probability of failure estimates for small diameter onshore pipelines (by failure cause).

Rank	Segment	Total Risk ($/km yr) Combined	Total Risk ($/km yr) Ext Cor	Total Risk ($/km yr) Gnd Mov	Total Risk ($/km yr) Int Cor	Total Risk ($/km yr) Mech Dmg	Total Risk ($/km yr) Other	Total Risk ($/km yr) SCC	Total Risk ($/km yr) Seam Ftg
3	B1	1.78E+04	3.51E+03	2.79E+02	1.61E+01	1.61E+01	1.40E+04	0.00E+00	0.00E+00
10	B2	1.14E+02	4.80E+01	2.42E-01	5.16E-02	3.41E-01	1.53E+01	4.98E+01	0.00E+00
11	B3	9.60E+01	6.47E+01	2.40E+00	5.32E-02	3.39E-01	1.51E+01	1.34E+01	0.00E+00
15	B4	6.58E+01	4.01E+01	2.72E-01	4.07E-02	1.05E-01	1.68E+01	8.44E+00	0.00E+00
19	C1	3.77E+01	3.35E-01	5.75E+00	6.15E-02	3.87E-02	3.15E+01	0.00E+00	0.00E+00
4	C2	1.76E+04	1.05E+02	2.89E+03	1.93E+01	1.39E+02	1.45E+04	0.00E+00	0.00E+00
5	D1	1.71E+04	2.63E+03	1.28E+03	8.92E+01	3.25E+02	1.28E+04	0.00E+00	0.00E+00
13	D2	7.64E+01	1.89E+01	1.50E+00	2.92E-01	2.34E-01	2.54E+01	3.01E+01	0.00E+00
14	D7	6.60E+01	1.41E+01	8.35E-01	7.02E-01	2.96E+00	4.46E+01	2.89E+00	0.00E+00
16	D8	5.88E+01	2.31E+01	4.05E-01	4.29E-01	6.46E+00	2.36E+01	4.77E+00	0.00E+00

Table 3.4 Total risk estimates for large diameter onshore pipelines (by failure cause).

Rank	Segment	Prob. Fail (per km yr) Combined	Prob. Fail (per km yr) Ext Cor	Prob. Fail (per km yr) Gnd Mov	Prob. Fail (per km yr) Int Cor	Prob. Fail (per km yr) Mech Dmg	Prob. Fail (per km yr) Other	Prob. Fail (per km yr) SCC	Prob. Fail (per km yr) Seam Ftg
3	B1	3.01E-04	9.99E-05	1.00E-06	4.57E-07	9.18E-08	2.00E-04	0.00E+00	0.00E+00
10	B2	1.37E-03	7.78E-04	1.00E-06	8.37E-07	1.53E-06	2.00E-04	3.89E-04	0.00E+00
11	B3	1.38E-03	1.06E-03	1.00E-05	8.70E-07	1.53E-06	2.00E-04	1.06E-04	0.00E+00
15	B4	8.59E-04	5.97E-04	1.00E-06	6.06E-07	4.20E-07	2.00E-04	5.97E-05	0.00E+00
19	C1	2.13E-04	2.88E-06	1.00E-05	5.30E-07	7.62E-08	2.00E-04	0.00E+00	0.00E+00
4	C2	2.14E-04	2.88E-06	1.00E-05	5.30E-07	7.62E-07	2.00E-04	0.00E+00	0.00E+00
5	D1	2.91E-04	8.16E-05	5.00E-06	2.77E-06	2.02E-06	2.00E-04	0.00E+00	0.00E+00
13	D2	5.53E-04	1.72E-04	5.00E-06	2.66E-06	8.55E-07	2.00E-04	1.72E-04	0.00E+00
14	D7	3.27E-04	1.05E-04	1.00E-06	5.25E-06	4.99E-06	2.00E-04	1.05E-05	0.00E+00
16	D8	5.27E-04	2.74E-04	1.00E-06	5.08E-06	1.95E-05	2.00E-04	2.74E-05	0.00E+00

Table 3.5 Probability of failure estimates for large diameter onshore pipelines (by failure cause).

Rank	Failure Cause	Segment	Total Risk ($/km yr)	Prob. Fail (per km yr)	Exp. Cost ($/km yr)	Exp. Fatal. (per km yr)
1	Mechanical Damage	A1	2.39E+04	1.39E-03	7.99E+03	7.96E-03
2	Mechanical Damage	D6	1.80E+04	9.83E-04	6.01E+03	6.00E-03
3	Other	C2	1.45E+04	2.00E-04	4.75E+03	4.87E-03
4	Other	B1	1.40E+04	2.00E-04	4.58E+03	4.70E-03
5	Other	D1	1.28E+04	2.00E-04	4.19E+03	4.30E-03
6	Mechanical Damage	A3	1.19E+04	6.87E-04	4.00E+03	3.94E-03
7	External Corrosion	A1	4.48E+03	1.27E-03	1.51E+03	1.49E-03
8	Stress Corrosion Cracking	D4	4.19E+03	3.42E-02	4.19E+03	0.00E+00
9	External Corrosion	B1	3.51E+03	9.99E-05	1.15E+03	1.18E-03
10	Ground Movement	C2	2.89E+03	1.00E-05	9.49E+02	9.73E-04
11	External Corrosion	D1	2.63E+03	8.16E-05	8.62E+02	8.82E-04
12	External Corrosion	D4	2.49E+03	3.42E-02	2.49E+03	0.00E+00
13	Stress Corrosion Cracking	A1	2.30E+03	3.18E-04	7.73E+02	7.63E-04
14	External Corrosion	A3	2.26E+03	6.40E-04	7.68E+02	7.47E-04
15	Other	D6	1.40E+03	2.00E-04	4.68E+02	4.67E-04
16	Ground Movement	D6	1.38E+03	5.00E-05	4.59E+02	4.61E-04
17	Other	A3	1.34E+03	2.00E-04	4.49E+02	4.45E-04
18	Other	A1	1.34E+03	2.00E-04	4.45E+02	4.45E-04
19	Ground Movement	D1	1.28E+03	5.00E-06	4.19E+02	4.30E-04
20	Mechanical Damage	C3	3.40E+02	1.99E-04	2.46E+02	4.65E-05
21	External Corrosion	A2	3.25E+02	2.93E-03	2.17E+02	5.44E-05
22	Mechanical Damage	D1	3.25E+02	2.02E-06	1.07E+02	1.09E-04
23	Ground Movement	B1	2.79E+02	1.00E-06	9.14E+01	9.39E-05
24	Stress Corrosion Cracking	A3	2.32E+02	3.20E-05	7.88E+01	7.67E-05
25	Stress Corrosion Cracking	A2	1.66E+02	7.32E-04	1.10E+02	2.79E-05
26	Mechanical Damage	C2	1.39E+02	7.62E-07	4.56E+01	4.66E-05
27	Other	C3	1.29E+02	2.00E-04	9.35E+01	1.79E-05
28	External Corrosion	D6	1.21E+02	3.21E-05	4.08E+01	4.02E-05
29	External Corrosion	C2	1.05E+02	2.88E-06	3.46E+01	3.53E-05
30	Internal Corrosion	D1	8.92E+01	2.77E-06	2.93E+01	3.00E-05
31	Mechanical Damage	A2	6.91E+01	1.45E-04	4.26E+01	1.32E-05
32	External Corrosion	C3	6.52E+01	1.81E-04	4.79E+01	8.64E-06
33	External Corrosion	B3	6.47E+01	1.06E-03	6.47E+01	0.00E+00
34	Stress Corrosion Cracking	B2	4.98E+01	3.89E-04	4.98E+01	0.00E+00

Table 3.6a Risk ranking of onshore pipelines (by failure cause).

Rank	Failure Cause	Segment	Total Risk ($/km yr)	Prob. Fail (per km yr)	Exp. Cost ($/km yr)	Exp. Fatal. (per km yr)
35	External Corrosion	B2	4.80E+01	7.78E-04	4.80E+01	0.00E+00
36	Other	D7	4.46E+01	2.00E-04	4.46E+01	0.00E+00
37	External Corrosion	B4	4.01E+01	5.97E-04	4.01E+01	0.00E+00
38	Other	A2	3.57E+01	2.00E-04	2.16E+01	7.08E-06
39	Other	C1	3.15E+01	2.00E-04	2.84E+01	1.51E-06
40	Stress Corrosion Cracking	D2	3.01E+01	1.72E-04	3.01E+01	0.00E+00
41	External Corrosion	D3	2.90E+01	5.30E-04	2.90E+01	0.00E+00
42	Stress Corrosion Cracking	D3	2.77E+01	2.65E-04	2.77E+01	0.00E+00
43	Ground Movement	A3	2.65E+01	1.00E-06	8.85E+00	8.83E-06
44	Other	D2	2.54E+01	2.00E-04	2.54E+01	0.00E+00
45	Ground Movement	C3	2.52E+01	1.00E-05	1.81E+01	3.55E-06
46	Mechanical Damage	D5	2.42E+01	1.21E-04	2.30E+01	6.09E-07
47	Other	D8	2.36E+01	2.00E-04	1.96E+01	2.03E-06
48	External Corrosion	D8	2.31E+01	2.74E-04	2.03E+01	1.39E-06
49	Internal Corrosion	C2	1.93E+01	5.30E-07	6.36E+00	6.49E-06
50	External Corrosion	D2	1.89E+01	1.72E-04	1.89E+01	0.00E+00
51	Ground Movement	A4	1.72E+01	1.00E-04	1.72E+01	0.00E+00
52	Other	B4	1.68E+01	2.00E-04	1.68E+01	0.00E+00
53	Other	D4	1.67E+01	2.00E-04	1.67E+01	0.00E+00
54	Mechanical Damage	B1	1.61E+01	9.18E-08	5.28E+00	5.41E-06
55	Internal Corrosion	B1	1.61E+01	4.57E-07	5.27E+00	5.40E-06
56	Other	B2	1.53E+01	2.00E-04	1.53E+01	0.00E+00
57	Other	B3	1.51E+01	2.00E-04	1.51E+01	0.00E+00
58	External Corrosion	A4	1.51E+01	3.18E-04	1.51E+01	0.00E+00
59	Other	D5	1.45E+01	2.00E-04	1.37E+01	3.94E-07
60	External Corrosion	D7	1.41E+01	1.05E-04	1.41E+01	0.00E+00
61	Stress Corrosion Cracking	B3	1.34E+01	1.06E-04	1.34E+01	0.00E+00
62	Internal Corrosion	D6	1.30E+01	3.45E-06	4.38E+00	4.32E-06
63	Other	D3	1.30E+01	2.00E-04	1.30E+01	0.00E+00
64	Other	A4	1.14E+01	2.00E-04	1.14E+01	0.00E+00
65	Internal Corrosion	A3	8.60E+00	2.43E-06	2.92E+00	2.84E-06
66	Internal Corrosion	A1	8.56E+00	2.43E-06	2.88E+00	2.84E-06
67	Mechanical Damage	A4	8.49E+00	5.20E-05	8.49E+00	0.00E-00
68	Stress Corrosion Cracking	B4	8.44E+00	5.97E-05	8.44E+00	0.00E-00

Table 3.6b Risk ranking of onshore pipelines (by failure cause).

Rank	Failure Cause	Segment	Total Risk ($/km yr)	Prob. Fail (per km yr)	Exp. Cost ($/km yr)	Exp. Fatal. (per km yr)
69	Mechanical Damage	D3	8.38E+00	4.80E-05	8.38E+00	0.00E+00
70	External Corrosion	D5	6.90E+00	1.18E-04	6.66E+00	1.20E-07
71	Stress Corrosion Cracking	D5	6.79E+00	5.90E-05	6.54E+00	1.22E-07
72	Mechanical Damage	D8	6.46E+00	1.95E-05	5.47E+00	4.95E-07
73	Ground Movement	C1	5.75E+00	1.00E-05	5.14E+00	3.02E-07
74	Mechanical Damage	D4	5.16E+00	2.67E-05	5.16E+00	0.00E+00
75	Stress Corrosion Cracking	D8	4.77E+00	2.74E-05	4.21E+00	2.80E-07
76	Mechanical Damage	D7	2.96E+00	4.99E-06	2.96E+00	0.00E+00
77	Stress Corrosion Cracking	D7	2.89E+00	1.05E-05	2.89E+00	0.00E+00
78	Ground Movement	A1	2.64E+00	1.00E-07	8.78E-01	8.82E-07
79	Ground Movement	B3	2.40E+00	1.00E-05	2.40E+00	0.00E+00
80	Ground Movement	D4	2.06E+00	1.00E-05	2.06E+00	0.00E+00
81	Ground Movement	D3	1.85E+00	1.00E-05	1.85E+00	0.00E+00
82	Stress Corrosion Cracking	A4	1.53E+00	1.59E-05	1.53E+00	0.00E+00
83	Ground Movement	D2	1.50E+00	5.00E-06	1.50E+00	0.00E+00
84	Ground Movement	D5	1.10E+00	5.00E-06	1.02E+00	3.92E-08
85	Ground Movement	D7	8.35E-01	1.00E-06	8.35E-01	0.00E+00
86	Internal Corrosion	D7	7.02E-01	5.25E-06	7.02E-01	0.00E+00
87	Internal Corrosion	D4	5.26E-01	7.23E-06	5.26E-01	0.00E+00
88	Internal Corrosion	D3	5.09E-01	9.28E-06	5.09E-01	0.00E+00
89	Internal Corrosion	D8	4.29E-01	5.08E-06	3.77E-01	2.59E-08
90	Ground Movement	D8	4.05E-01	1.00E-06	3.24E-01	4.05E-08
91	Internal Corrosion	C3	4.02E-01	1.11E-06	2.95E-01	5.32E-08
92	Mechanical Damage	B2	3.41E-01	1.53E-06	3.41E-01	0.00E+00
93	Mechanical Damage	B3	3.39E-01	1.53E-06	3.39E-01	0.00E+00
94	External Corrosion	C1	3.35E-01	2.88E-06	3.13E-01	1.10E-08
95	Internal Corrosion	D5	3.14E-01	5.36E-06	3.03E-01	5.45E-09
96	Internal Corrosion	D2	2.92E-01	2.66E-06	2.92E-01	0.00E+00
97	Ground Movement	B4	2.72E-01	1.00E-06	2.72E-01	0.00E+00
98	Internal Corrosion	A2	2.70E-01	2.43E-06	1.80E-01	4.51E-08
99	Ground Movement	B2	2.42E-01	1.00E-06	2.42E-01	0.00E+00
100	Mechanical Damage	D2	2.34E-01	8.55E-07	2.34E-01	0.00E+00
101	Internal Corrosion	A4	1.15E-01	2.43E-06	1.15E-01	0.00E+00
102	Mechanical Damage	B4	1.05E-01	4.20E-07	1.05E-01	0.00E+00

Table 3.6c Risk ranking of onshore pipelines (by failure cause).

Rank	Failure Cause	Segment	Total Risk ($/km yr)	Prob. Fail (per km yr)	Exp. Cost ($/km yr)	Exp. Fatal. (per km yr)
103	Ground Movement	A2	6.56E-02	1.00E-07	3.76E-02	1.40E-08
104	Internal Corrosion	C1	6.15E-02	5.30E-07	5.75E-02	2.02E-09
105	Internal Corrosion	B3	5.32E-02	8.70E-07	5.32E-02	0.00E+00
106	Internal Corrosion	B2	5.16E-02	8.37E-07	5.16E-02	0.00E+00
107	Internal Corrosion	B4	4.07E-02	6.06E-07	4.07E-02	0.00E+00
108	Mechanical Damage	C1	3.87E-02	7.62E-08	3.58E-02	1.45E-09
109	Seam Weld Fatigue	A1	0.00E+00	0.00E+00	0.00E+00	0.00E+00
110	Seam Weld Fatigue	A2	0.00E+00	0.00E+00	0.00E+00	0.00E+00
111	Seam Weld Fatigue	A3	0.00E+00	0.00E+00	0.00E+00	0.00E+00
112	Seam Weld Fatigue	A4	0.00E+00	0.00E+00	0.00E+00	0.00E+00
113	Stress Corrosion Cracking	B1	0.00E+00	0.00E+00	0.00E+00	0.00E+00
114	Seam Weld Fatigue	B1	0.00E+00	0.00E+00	0.00E+00	0.00E+00
115	Seam Weld Fatigue	B2	0.00E+00	0.00E+00	0.00E+00	0.00E+00
116	Seam Weld Fatigue	B3	0.00E+00	0.00E+00	0.00E+00	0.00E+00
117	Seam Weld Fatigue	B4	0.00E+00	0.00E+00	0.00E+00	0.00E+00
118	Stress Corrosion Cracking	C1	0.00E+00	0.00E+00	0.00E+00	0.00E+00
119	Seam Weld Fatigue	C1	0.00E+00	0.00E+00	0.00E+00	0.00E+00
120	Stress Corrosion Cracking	C2	0.00E+00	0.00E+00	0.00E+00	0.00E+00
121	Seam Weld Fatigue	C2	0.00E+00	0.00E+00	0.00E+00	0.00E+00
122	Stress Corrosion Cracking	C3	0.00E+00	0.00E+00	0.00E+00	0.00E+00
123	Seam Weld Fatigue	C3	0.00E+00	0.00E+00	0.00E+00	0.00E+00
124	Stress Corrosion Cracking	D1	0.00E+00	0.00E+00	0.00E+00	0.00E+00
125	Seam Weld Fatigue	D1	0.00E+00	0.00E+00	0.00E+00	0.00E+00
126	Seam Weld Fatigue	D2	0.00E+00	0.00E+00	0.00E+00	0.00E+00
127	Seam Weld Fatigue	D3	0.00E+00	0.00E+00	0.00E+00	0.00E+00
128	Seam Weld Fatigue	D4	0.00E+00	0.00E+00	0.00E+00	0.00E+00
129	Seam Weld Fatigue	D5	0.00E+00	0.00E+00	0.00E+00	0.00E+00
130	Stress Corrosion Cracking	D6	0.00E+00	0.00E+00	0.00E+00	0.00E+00
131	Seam Weld Fatigue	D6	0.00E+00	0.00E+00	0.00E+00	0.00E+00
132	Seam Weld Fatigue	D7	0.00E+00	0.00E+00	0.00E+00	0.00E+00
133	Seam Weld Fatigue	D8	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table 3.6d Risk ranking of onshore pipelines (by failure cause).

Rank	Segment	Total Risk ($/km yr)	Prob. Fail (per km yr)	Exp. Cost ($/km yr)	Exp. Fatal. (per km yr)
1	S2	1.06E+04	1.63E-03	6.68E+03	1.97E-03
2	S3	5.10E+03	4.05E-03	4.86E+03	1.19E-04
3	S5	4.59E+03	4.05E-03	4.47E+03	6.05E-05
4	S1	4.66E+02	4.36E-04	4.34E+02	1.62E-05
5	S4	1.80E+02	2.47E-04	1.80E+02	3.28E-08

Table 3.7 Risk estimates for offshore pipelines (all causes combined).

Rank	Segment	Total Risk ($/km yr) Combined	Total Risk ($/km yr) Ext Corr	Total Risk ($/km yr) Gnd Mov	Total Risk ($/km yr) Int Corr	Total Risk ($/km yr) Mech Dmg	Total Risk ($/km yr) Nat Haz Dmg	Total Risk ($/km yr) Other	Total Risk ($/km yr) SCC	Total Risk ($/km yr) Weld Ftg
4	S1	4.66E+02	0.06572	0.084813	0.87204	153.05	120.32	191.93	0	0
1	S2	1.06E+04	0.22001	0.44235	2.9194	5540.8	4356.1	727.42	0	0
2	S3	5.10E+03	111.86	0.081117	102.04	2632.9	2069.9	181.62	0	0
5	S4	1.80E+02	0.0575	0.065346	0.76297	8.857	6.9632	163.1	0	0
3	S5	4.59E+03	107.91	0.07	98.44	2358.65	1854.33	169.88	0	0

Table 3.8 Total risk estimates for offshore pipelines (by failure cause).

Rank	Segment	Prob. Fail (per km yr) Combined	Prob. Fail (per km yr) Ext Corr	Prob. Fail (per km yr) Gnd Mov	Prob. Fail (per km yr) Int Corr	Prob. Fail (per km yr) Mech Dmg	Prob. Fail (per km yr) Nat Haz Dmg	Prob. Fail (per km yr) Other	Prob. Fail (per km yr) SCC	Prob. Fail (per km yr) Weld Ftg
4	S1	4.36E-04	9.1409E-08	0.00000005	1.2129E-06	0.00011353	8.9256E-05	0.00023156	0	0
1	S2	1.63E-03	9.1409E-08	0.00000005	1.2129E-06	0.00078297	0.00061556	0.00023156	0	0
2	S3	4.05E-03	0.0001662	0.00000005	0.00015161	0.0019574	0.0015389	0.00023156	0	0
5	S4	2.47E-04	9.1409E-08	0.00000005	1.2129E-06	7.8297E-06	6.1555E-06	0.00023156	0	0
3	S5	4.05E-03	0.0001662	0.00000005	0.00015161	0.0019574	0.0015389	0.00023156	0	0

Table 3.9 Probability of failure estimates for offshore pipelines (by failure cause).

Rank	Failure Cause	Segment	Total Risk ($/km yr)	Prob. Fail (per km yr)	Exp. Cost ($/km yr)	Exp. Fatal. (per km yr)
1	Mechanical Damage	S2	5.54E+03	7.83E-04	3.47E+03	1.03E-03
2	Natural Hazard Damage	S2	4.36E+03	6.16E-04	2.73E+03	8.13E-04
3	Mechanical Damage	S3	2.63E+03	1.96E-03	2.51E+03	6.38E-05
4	Mechanical Damage	S5	2.36E+03	1.96E-03	2.29E+03	3.22E-05
5	Natural Hazard Damage	S3	2.07E+03	1.54E-03	1.97E+03	5.01E-05
6	Natural Hazard Damage	S5	1.85E+03	1.54E-03	1.80E+03	2.53E-05
7	Other	S2	7.27E+02	2.32E-04	4.77E+02	1.25E-04
8	Other	S1	1.92E+02	2.32E-04	1.79E+02	6.41E-06
9	Other	S3	1.82E+02	2.32E-04	1.76E+02	2.82E-06
10	Other	S5	1.70E+02	2.32E-04	1.67E+02	1.53E-06
11	Other	S4	1.63E+02	2.32E-04	1.63E+02	2.82E-08
12	Mechanical Damage	S1	1.53E+02	1.14E-04	1.42E+02	5.47E-06
13	Natural Hazard Damage	S1	1.20E+02	8.93E-05	1.12E+02	4.30E-06
14	External Corrosion	S3	1.12E+02	1.66E-04	1.10E+02	1.12E-06
15	External Corrosion	S5	1.08E+02	1.66E-04	1.06E+02	7.67E-07
16	Internal Corrosion	S3	1.02E+02	1.52E-04	1.00E+02	1.02E-06
17	Internal Corrosion	S5	9.84E+01	1.52E-04	9.70E+01	7.00E-07
18	Mechanical Damage	S4	8.86E+00	7.83E-06	8.85E+00	2.55E-09
19	Natural Hazard Damage	S4	6.96E+00	6.16E-06	6.96E+00	2.01E-09
20	Internal Corrosion	S2	2.92E+00	1.21E-06	1.96E+00	4.79E-07
21	Internal Corrosion	S1	8.72E-01	1.21E-06	8.24E-01	2.42E-08
22	Internal Corrosion	S4	7.63E-01	1.21E-06	7.63E-01	8.15E-11
23	Ground Movement	S2	4.42E-01	5.00E-08	2.75E-01	8.38E-08
24	External Corrosion	S2	2.20E-01	9.14E-08	1.48E-01	3.61E-08
25	Ground Movement	S1	8.48E-02	5.00E-08	7.62E-02	4.33E-09
26	Ground Movement	S3	8.11E-02	5.00E-08	7.63E-02	2.40E-09
27	Ground Movement	S5	7.00E-02	5.00E-08	7.00E-02	1.07E-09
28	External Corrosion	S1	6.57E-02	9.14E-08	6.21E-02	1.83E-09
29	Ground Movement	S4	6.53E-02	5.00E-08	6.53E-02	2.40E-11
30	External Corrosion	S4	5.75E-02	9.14E-08	5.75E-02	6.14E-12
31	Stress Corrosion Cracking	S1	0.00E+00	0.00E+00	0.00E+00	0.00E+00
32	Girth Weld Fatigue	S1	0.00E+00	0.00E+00	0.00E+00	0.00E+00
33	Stress Corrosion Cracking	S2	0.00E+00	0.00E+00	0.00E+00	0.00E+00
34	Girth Weld Fatigue	S2	0.00E+00	0.00E+00	0.00E+00	0.00E+00
35	Stress Corrosion Cracking	S3	0.00E+00	0.00E+00	0.00E+00	0.00E+00
36	Girth Weld Fatigue	S3	0.00E+00	0.00E+00	0.00E+00	0.00E+00
37	Stress Corrosion Cracking	S4	0.00E+00	0.00E+00	0.00E+00	0.00E+00
38	Girth Weld Fatigue	S4	0.00E+00	0.00E+00	0.00E+00	0.00E+00
39	Stress Corrosion Cracking	S5	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	Girth Weld Fatigue	S5	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table 3.10 Risk ranking of offshore pipelines (by failure cause).

4. DISCUSSION OF RESULTS

A summary of the line sections analyzed and the results obtained using the *PIRAMID*™ Prioritization software was submitted to representatives of all operating companies and government agencies participating in the program validation exercise. A one-day workshop was then held in September of 1998 to review the results obtained and solicit comments on model performance, including suggestions for future improvements. (The material presented by C-FER at the workshop to stimulate a discussion of the validity of the models used in the onshore and offshore prioritization programs is contained in Appendices C and D, respectively.)

General observations on the performance of the prioritization models applicable to both onshore and offshore pipeline systems are summarized in Section 4.1. Specific suggestions for improvements to the accuracy and repeatability of estimates generated using the failure probability and consequences estimation models are listed in Section 4.2, for the onshore pipeline prioritization program.

Note that no specific suggestions were made at the workshop for improvements to the offshore pipeline prioritization program. This stems from the fact that no offshore pipeline operating companies are directly involved in the *PIRAMID*™ development initiative. (At this time offshore pipeline interests are represented solely by Canadian and American government agencies; specifically Natural Resources Canada through the Geological Survey of Canada, and the US Department of the Interior through the Minerals Management Service.)

4.1 General

It was found that the overall risk rankings obtained using the prioritization models, for both onshore and offshore pipelines, are broadly consistent with expectations. Sections subjectively assessed to have relatively low and high probabilities of failure were correctly delineated and low and high consequences areas were clearly reflected in the total risk estimates. The ranking of individual pipelines by the estimated risks levels associated with individual failure causes was found to correctly target the failure mechanisms expected to contribute most to the failure potential for the lines in question.

With regard to the accuracy of models implemented in the onshore pipeline prioritization program, specific questions were raised with regard to some of the probability estimation models. Concerns were expressed about the external corrosion model and the effect of coating type, coating condition factors, and operating temperature on the estimated corrosion failure frequency. Tape coated lines in either good or bad condition were thought to be unduly penalized (*i.e.*, the failure probability estimate was perceived to be too high, relative to that for other coating systems) and the relative line operating temperature was observed to have a dominating effect on the failure frequency estimate that is not directly supported by operator experience. Concern was also expressed about the general form of the frequency estimation model for SCC because the assumed linkage between a susceptibility to SCC failure and the

occurrence of external corrosion (implicit in the current model), is not typically representative of actual operating experience. Finally, it was observed that the estimated potential for failure by mechanical damage in urban areas appears to be somewhat overestimated, perhaps due to a lack of acknowledgement in the frequency estimation model of the perceived benefits of efforts directed at enhancing public awareness.

With regard to the consequence estimation models, some concern was expressed about the lack of flexibility imposed by the format employed in *PIRAMID*™ for the characterization of land use (as it relates to population and property densities), and the assumptions inherent in the model employed to estimate the financial costs of service interruption. In a more general context it was noted that the consequence estimation models currently implemented appear to provide a more accurate representation of the true range of failure consequences (*i.e.*, several orders of magnitude) than available alternative models, most of which are based on subjective characterizations of failure impact. Since ranking models that underestimate the range of failure consequences will tend to produce a ranking that is skewed towards high probability sections, the implication is that the *PIRAMID*™ approach will provide a more balanced characterization of operating risk.

Finally, with regard to repeatability issues, a number of model input parameters (*i.e.*, line attributes) were identified as having the potential for differing interpretations of what is to be specified. This problem was attributed to one of two factors: a lack of clarity in the stated definition of the parameter (and a lack of appreciation of how and where the parameter is used), or in the case of attributes that are to be defined from a predefined list of choices, a lack of sufficient category choices to adequately reflect the range of possible values.

4.2 Onshore Pipeline System Prioritization Models

4.2.1 Accuracy Issues

4.2.1.1 Comments on Probability Estimation Models

External Corrosion

- Define separate line attributes for *electrical interference* and *casing short* (as opposed to the current combined interference attribute) to acknowledge the potential for different effects on cathodic protection system effectiveness.
- Expand the *coating type* category list and provide more explicit category definitions, or consider making *coating type* user-definable.
- Revise the *coating type* and *coating condition* factors to accommodate lines where the type and condition of the coating in the vicinity of field joints is distinctly different from that of

the pipe body (consider a blended coating type and/or condition that avoids the need to define a distinct line section at each field joint location).

- Revisit the *coating type* and *coating condition* factors, and their combined effect on corrosion susceptibility (*e.g.*, tape coat in good condition appears to be excessively penalized).
- Revisit the combined effect of *coating condition* and *coating shielding* factors on the corrosion susceptibility of tape coated lines since tape coat in poor condition generally implies the presence of coating shielding (*e.g.*, make shielding a coating condition factor for tape coated lines).
- Revisit the algorithm involving *operating temperature* in light of observed sensitivity of failure rate estimate to this attribute.
- Acknowledged the implicit effect of *operating temperate* on *coating condition* for some coating types.
- Consider replacing the *soil corrosivity* factor with a set of line attributes that collectively characterize environment corrosivity, or de-couple soil corrosivity from soil resistivity and/or topography and soil texture, and make it a user-definable attribute.
- Consider introducing an attribute (or set of attributes) to reflect the beneficial effect of previous in-line inspections and/or hydrostatic tests.
- Consider the merits of adopting a fault tree approach rather than following an index multiplier approach.

Internal Corrosion

- Consider replacing the *product corrosivity* factor with a set of line attributes that collectively characterize product corrosivity, or consider making *product corrosivity* a user-definable attribute.
- Consider introducing an attribute(or set of attributes) to reflect the beneficial effect of previous in-line inspections and/or hydrostatic tests.

Mechanical Damage

- Define separate line attributes for *crossings* and *special terrain* (as opposed to the current combined attribute) and add utility crossings to the *crossing type* attribute list.
- Revise the frequency estimation model to include attributes that reflect the perceived benefit, in terms of reduced hit frequency, associated with public awareness programs.
- Revisit the burial depth categories to ensure that typical pipeline burial depths do not fall on the transition between the chosen depth range categories.

Ground Movement

Discussion of Results

- Expand the *pipe joint type* category list and provide more explicit category definitions tied to welding process, inspection quality, vintage, *etc.*, or consider making *pipe joint type* user-definable.
- Consider replacing the current *ground movement potential* and *pipe failure given movement* attributes, which are difficult to define without prior geotechnical and/or pipe soil interaction analysis, with an attribute set that reflects: ground movement type (lateral vs. axial), movement extent, movement rate and soil type.

Stress Corrosion Cracking

- De-couple the stress corrosion cracking failure rate estimate from the external corrosion model and develop an entirely separate model for SCC susceptibility.
- Distinguish between "classical" and "non-classical" forms of SCC.
- Consider introducing an attribute (or set of attributes) to reflect the beneficial effect of previous in-line inspections and/or hydrostatic tests.
- Consider the merits of adopting a fault tree approach rather than following an index multiplier approach.

Seam Weld Fatigue

- Expand the *seam weld type* category list and provide more explicit category definitions tied to weld process, inspection quality, vintage, *etc.*, or consider making *seam weld type* user-definable.
- Consider introducing an attribute (or set of attributes) to reflect the beneficial effect of previous in-line inspections and/or hydrostatic tests.

4.2.1.2 Comments on Consequence Estimation Models

Release Volume

- Revise the current block valve specification approach to facilitate specification by valve location rather than by valve spacing.
- Revisit the current approach to representing the effectiveness of leak detection systems because the attributes *detectable release volume* and *time to leak detection* are difficult to specify and do not fully reflect the action of leak detection systems.

Hazard Type

- Revise the immediate ignition probability estimation model for natural gas pipelines to make ignition probability also depend on *line diameter* and *operating pressure*.
- Revisit the event tree and assess the applicability of the current structure for release hazards associated with buoyant vapours (*i.e.*, natural gas).

Discussion of Results

- Revisit the event tree and assess whether the combined effect of delayed hazard occurrence, following immediate hazard occurrence, is adequately addressed.

Number of Fatalities and Property Damage Cost

- Expand the *land use type* categories, or make them user-definable, and consider de-coupling population density and property values from *land use type*.

Service Interruption Cost

- Revise the current interruption cost model (for transmission lines), which is based on nominated and delivered monthly volumes and billing abatement thresholds, to acknowledge seasonal variations and the potential for alternate delivery paths.

- Introduce an alternate approach to service interruption cost estimation (for distribution lines in particular) that assigns a user-defined fixed cost and a time dependent variable cost to service interruption events occurring in both summer and winter seasons.

4.2.2 Comments on Repeatability Issues

- Clarify the definition of *operating pressure* (*i.e.*, actual operating pressure profile vs. MAOP).

- Clarify the definitions of *operating pressure range* and *cumulative number of pressure cycles* as they relate to seam weld fatigue failure estimation.

- Clarify the definitions of *line volume*, *billing abatement threshold*, and *transportation distance* as they relate to service interruption cost estimation.

- Clarify the distinction between *near field terrain* and *far field terrain* types as they relate to spill clean-up and environmental damage estimation.

- Consider changing the format of the product *flow rate* attribute from mass flow units to volume flow units, since *flow rate* is not typically given in mass flow units.

5. CONCLUSIONS AND RECOMMENDATIONS

The program validation exercise carried out in this project provided a mechanism for the evaluation of the adequacy of both the probability and consequence estimation models implemented in the *PIRAMID*™ software that has been developed for pipeline system prioritization. The specific programs addressed in this exercise include *PIRAMID*™ Onshore Prioritization - Version 1.4 and *PIRAMID*™ Offshore Prioritization - Version 1.4 (both released in February of 1998).

The general findings of this model validation process are as follows:

- The overall risk rankings obtained using the prioritization models, for both onshore and offshore pipelines, are broadly consistent with expectations.
- Sections subjectively assessed to have relatively low and high probabilities of failure were correctly delineated and both low and high consequence areas were clearly reflected in the total risk estimates.
- The ranking of individual pipelines by the estimated risks levels associated with individual failure causes was found to correctly target the failure mechanisms expected to contribute most to the failure potential for the lines in question.

In addition, it was found that the consequence estimation models currently implemented appear to provide a more accurate representation of the true range of failure consequences (*i.e.*, several orders of magnitude) than available alternative models, most of which are based on subjective characterizations of failure impact. Since ranking models that underestimate the range of failure consequences will tend to produce a ranking that is skewed towards high probability sections, the implication is that the *PIRAMID*™ prioritization models provide a more balanced characterization of operating risk.

With specific regard to the prioritization models developed for onshore pipeline systems, some areas of concern were identified, particularly with regard to the perceived accuracy of models developed for estimating the probabilities of failure due to external metal loss corrosion, stress corrosion cracking and mechanical damage. In terms of repeatability issues, some model input parameters (*i.e.*, line attributes) were identified as having the potential for differing interpretations of what is to be specified.

Specific comments on, and suggestions for improvements to, the probability and consequence estimation models applicable to onshore pipelines, as provided by companies and agencies participating in the *PIRAMID*™ development initiative, are summarized in Section 4.2 of this report. The listed comments pertaining to the accuracy and repeatability of the probability estimation models are currently being addressed in a follow-on project in the *PIRAMID*™ development program (Project 8 in the approved works scope for the 1998 budget year), which involves revisions to the prioritization models. The issues raised pertaining to the consequence estimation models are being addressed in another follow-on project (Project 5 in the approved

works scope for the 1999 budget year), the scope of which encompasses general *PIRAMID*™ model and software improvements.

Note that no specific comments were received on the probability and consequence estimation models associated with the offshore pipeline system prioritization software. This stems from the fact that no offshore pipeline operators were available to participate in the validation process (*i.e.*, test cases for offshore pipelines were submitted by operating companies that do not belong to the *PIRAMID*™ development program through the US Minerals Management Service). It is, therefore, recommended that accuracy and repeatability issues, as they relate to the models developed for offshore pipelines, be revisited in the near future when more direct involvement of offshore pipeline operating companies can be obtained.

APPENDIX A

Description of Line Attributes for Onshore Pipelines (extract from PIRAMID™ Prioritization User's Guide – Appendix B)

Appendix A

The attributes that must be specified to fully define each pipeline are defined as follows (see also Tables A.1 and A.2):

- **Product Set** The list of products transported through the line segment and the relative amount of time that each product type is assumed to be in the line. Note that the specification of multiple product types is assumed to imply batched product shipping.
- **Pipeline Diameter** The outside diameter of the line pipe.
- **Pipe Wall Thickness** The wall thickness of the line pipe.
- **Pipe Body Yield Strength** The specified yield strength of the line pipe steel.
- **Pipe Body Seam Weld Type** A relative indication of line pipe seam weld quality (*i.e.*, seamless, high quality, suspect quality, or poor quality). The characterization is intended to reflect the relative number and size of planar defects introduced during the seam welding process.
- **Pipe Joint Type** The type of pipe joint (weld vs. mechanical joint) and a relative indication of joint quality for welded butt joints (*i.e.*, high quality, average quality, or poor quality). The characterization is intended to reflect the strength and ductility of the joint.
- **Line Age** The age of the line segment since initial construction.
- **Elevation Profile** The relative elevation profile of the line defined at the start and end points of the line and selected reference points along the length of the line. Note that the location of intermediate points should be chosen to adequately characterize the elevation profile given that the program uses linear interpolation to infer the elevation at all locations between specified reference points.
- **Pressure Profile** The anticipated maximum operating pressure in the line defined at the start and end points of the line and selected reference points along the length of the line. Note that the location of intermediate points should be chosen to adequately characterize the pressure profile given that the program uses linear interpolation to infer the line pressure at all locations between specified reference points. Note also that the specified pressure should reflect an upper bound pressure profile associated with likely worst case operating conditions including, for example, periodic line pack or shut in.
- **Operating Pressure Range** The pressure range associated with cyclic fluctuations in line pressure during routine operation. Note that complex pressure vs. time loading histories must be characterized by a representative single value pressure range and a cumulative number of pressure cycles (see also Cumulative Number of Pressure Cycles).
- **Cumulative Number of Pressure Cycles** The effective number of pressure cycles experienced by the line since initial construction. Note that complex pressure vs. time loading histories must be characterized by a representative single value pressure range and a cumulative number of pressure cycles (see also Operating Pressure Range).
- **Operating Temperature** The average temperature of the product being transported through the line. Note that pipe body temperature is assumed to be equal to the product temperature.
- **Product Flow Rate** The product mass flow rate through the line segment under normal operating conditions. Note that a negative value implies a flow direction opposite to the direction of increasing KP distances.
- **Line Volume** The average nominated or tendered monthly flow volume, expressed as a percentage of pipeline through-put capacity.

- **Billing Abatement Threshold** The volume of product that must be delivered to avoid a service interruption cost penalty, expressed as a percentage of the nominated or tendered monthly volume.
- **Product Transport Distance** The total distance over which products traveling through the line segment are transported.
- **Block Valve Spacing** The spacing between isolation valves along the length of the line segment.
- **Time to Block Valve Closure** The time required to close the block valves measured from the time when the leak is first detected.
- **Detectable Release Volume** The maximum volume of product that can be lost from the line before leak detection equipment triggers a leak detection alarm. Note that it is assumed that steps will be taken to close all block valves immediately following the detection of a large leak or a rupture.
- **Time to Leak Detection** The time required to detect a small leak given that small leaks may only be detected by periodic line patrols or notification by third parties.
- **Time to Leak Stoppage** The time required by the operator to locate and repair a small leak measured from the time when the leak is first detected.
- **Depth of Cover** The depth of pipeline burial below ground surface.
- **Adjacent Land Use** The type of land usage immediately adjacent to the pipeline right-of-way (*i.e.*, industrial, commercial, residential-urban, residential-rural, agricultural, parkland-forested, parkland-other, remote-forested, or remote-other).
- **ROW Accessibility** A relative characterization of the accessibility of the pipeline to line repair equipment in terms of distance from maintenance personnel and equipment and potential difficulty of access to right-of-way (*i.e.*, near [easy access] or far [difficult access]).
- **ROW Condition** A relative characterization of the effectiveness of the maintained condition of the right-of-way and explicit signage in making contractors aware of the presence of the pipeline (*i.e.*, excellent, above average, average, below average, and poor).
- **ROW Patrol Frequency** The time interval between periodic right-of-way patrols (*i.e.*, three or more times per week, twice per week, weekly, bi-weekly, or monthly or less).
- **Notification / Response System** An indication of the existence of a one-call notification system and, where a system exists, a relative characterization of the associated level of public awareness (*i.e.*, high awareness, average awareness, low awareness).
- **Crossing Type / Special Terrain** A characterization of the type of crossing (*i.e.*, road/rail, river/stream, or aerial) or special terrain feature (*i.e.*, bog/muskeg, marsh/swamp, or lake) encountered by the pipeline as it affects construction activity levels, line repair costs and service interruption times.
- **Near Field Terrain** A characterization of the right-of-way soil type in terms of water permeability, for dry ground conditions, or surface water conditions, for submerged ground conditions as it affects liquid spill movement and clean-up potential (*i.e.*, ground - low permeability [clay/shale], ground - moderate permeability [silt/till], ground - high permeability [sand/gravel], waterlogged ground mass [bog/muskeg], water covered vegetation [marsh/swamp], static water [pond/lake], slow moving water, or fast moving water).
- **General Soil Corrosivity** A characterization of the relative degree to which the electrochemistry of the soil surrounding the pipe is conducive to promoting metal loss

corrosion. The soil corrosivity categories are associated with specific soil resistivity ranges and in the absence of soil resistivity data can be assumed to correspond to distinct soil drainage and texture categories (see below).

Soil Corrosivity	Resistivity (ohm/cm)	Soil Drainage - Texture
low	> 10,000	excessively drained - coarse texture
below average	5000 - 10,000	well drained - moderately coarse texture, or poorly drained - coarse texture
average	2000 - 5000	well drained - moderately fine texture, or poorly drained - moderately coarse texture, or very poorly drained with high steady water table
above average	1000 - 2000	well drained - fine texture, or poorly drained - moderately fine texture, or very poorly drained with fluctuating water table
high	< 1000	poorly drained - fine texture, or mucks, peats with fluctuating water table

- **SCC Potential of Soil Environment** A subjective characterization of the degree to which the soil conditions surrounding the pipe are considered conducive to promoting stress corrosion cracking (*i.e.*, no potential, unlikely potential, likely potential, definite potential).
- **External Pipe Coating Type** The type of external coating applied to the pipeline (*i.e.*, polyethylene/epoxy, coal tar, asphalt, tape coat, none [bare pipe]).
- **External Pipe Coating Condition** A relative characterization of the integrity of the external coating compared to a typical instance of the selected coating type (*i.e.*, above average, average, below average).
- **Cathodic Protection Level** An estimate of the adequacy and uniformity of the voltage potential generated by the cathodic protection system. The cathodic protection level categories are associated with specific characterizations of voltage adequacy and uniformity (see below).

Cathodic Protection Level	Characterization
above average	adequate voltage, uniform level
average	adequate average voltage, some variability
below average	inadequate voltage and/or high variability
no cathodic protection	———

- **Presence of Coating Shielding** An indication of whether or not the form of coating damage and the coating type are associated with a lack of effective cathodic protection at exposed locations on the pipe wall (*i.e.*, yes or no).
- **Electrical Interference of Casting Short** An indication of whether or not stray electrical currents or electrical shorting is contributing to a lack of effective cathodic protection at exposed locations on the pipe wall (*i.e.*, yes or no).
- **Product Corrosivity** A characterization of the relative corrosivity of the product set transported through the pipeline. The product corrosivity categories are associated with specific corrosion growth rate ranges (see below).

Product Corrosivity	Growth Rate (mm/yr)
negligible	< 0.02
low	0.02 to 0.1
moderate	0.1 to 0.5
high	0.5 to 2.5
extreme	> 2.5

- **Ground Movement Potential** An estimate of the frequency of occurrence of significant ground movement events on the right-of-way. The ground movement potential categories are associated with specific order-of-magnitude frequency values (see below).

Movement Potential	Frequency (events per km year)
Negligible	≤ 1 in 100,000
Low	1 in 10,000
Moderate	1 in 1000
High	1 in 100
Extreme	≥ 1 in 10

- **Pipe Damage Potential** An estimate of the likelihood of pipeline failure in the event of a significant ground movement event. The damage potential categories are associated with specific order-of-magnitude probability values (see below).

Damage Potential	Failure Probability (per movement event)
Low	≤ 1 in 100
Moderate	1 in 10
High	1 in 1

- **Surface Water within 300 m** The distance to the nearest perennial surface water feature.
- **Drinking Water within 5 km*** The distance to surface or groundwater used for drinking and the availability of an alternate supply (*i.e.*, not available, difficult to obtain, or readily available).
- **Other Water within 5 km***The distance to surface or groundwater used for purposes other than drinking water and the type of other use (*i.e.*, recreational purposes, commercial food preparation, livestock watering, irrigation or other food chain uses).
- **Land Use within 5 km*** The type of and distance to the adjacent land usage (*i.e.*, residential, agricultural, parkland, or commercial/industrial) with the highest potential for human exposure to contaminated soil.
- **Sensitive Environment within 10 km** The distance to sensitive environments defined to include sensitive aquatic environments, nature preserves, habitats for endangered species, sensitive forest reserves, national parks or forests, etc.
- **Sensitive Groundwater within 10 km** The distance to important or susceptible groundwater resources.

* Note, the predefined set of choices presented to the user for the specification of these attributes are listed in order of their potential for environmental damage. To correctly characterize the environmental impact associated with this attribute, the user should select the first choice in the list that applies to the line section in question.

Appendix A

No.	Attribute Description	Attribute Name	Input Type[2]	Failure Mechanism Affected[1]						
				External Corrosion	Internal Corrosion	Mechanical Damage	Ground Movement	Cracking (SCC)	Cracking (weld fatigue)	Other Causes
0	Product type	Product								
1	Pipe Diameter	PipeDia	S1					X	X	
2	Pipe Wall Thickness	PipeWall	S1	X	X	X		X	X	
3	Pipe Body Yield Strength	PipeYield	S1			X		X	X	
4	Pipe Body Seam Weld Type	SeamType	S2						X	
5	Pipe Joint Type	JointType	S2				X			
6	Line Age	LineAge	S1	X	X			X		
7	Line Elevation Profile	ElevProfile	C1							
8	Operating Pressure Profile	PressProfile	C1					X	X	
9	Operating Pressure Range	PressRange	S1					X	X	
10	Cumulative Number of Pressure Cycles	PressCycle	S1						X	
11	Operating Temperature	LineTemp	S1	X				X		
12	Product Flow Rate (sign denotes flow direction)	FlowRate	S1							
13	Line Volume (% of line capacity)	CapFraction	S1							
14	Billing Abatement Threshold (% of nominated volume)	BAT	S1							
15	Product Transportation Distance	TransDist	S1							
16	Block Valve Spacing	ValveSpace	S1							
17	Time to Block Valve Closure	TimeClose	S1							
18	Detectable Release Volume	VolDetect	S1							
19	Time to Leak Detection	TimeDetect	S1							
20	Time to Leak Stoppage (from time of detection)	TimeStop	S1							
21	Depth of cover	Cover	S1			X				
22	Adjacent Land Use	AdjLand	S2			X				
23	ROW Accessibility	ROWaccess	S2							
24	ROW Condition	ROWcond	S2			X				
25	ROW Patrol Frequency	ROWpatrol	S2			X				
26	Notification & Response System	Notify	S2			X				
27	Crossing Type / Special Terrain Features	Crossing	S2			X				
28	Near Field Terrain Characteristics	NFTerrain	S2							
29	General Soil Corrosivity	SoilCorrode	S2	X				X		
30	SCC Potential of Soil Environment	SCCPotential	S2					X		
31	External Pipe Coating Type	ExtCoating	S2	X				X		
32	External Pipe Coating Condition	CoatCond	S2	X				X		
33	Cathodic Protection Level	CPLevel	S2	X				X		
34	Presence of Coating Shielding	CoatShield	S2	X				X		
35	Presence of Electrical Interference or Casing Short	Interference	S2	X				X		
36	Product Corrosivity	ProdCorrode	S2		X					
37	Ground Movement Potential	GndMovPot	S2				X			
38	Pipe Fail Potential given Ground Movement	GndFailPot	S2				X			
39	Surface water within 300m	SrfWater	S2							
40	Drinking Water within 5 km	DrkWater	S2							
41	Other Water within 5 km	OthWater	S2							
42	Land Use within 5 km	DirExposure	S2							
43	Sensitive Environment within 10 km	SensEnviro	S2							
44	Sensitive Groundwater within 10 km	SensGndWtr	S2							

Note 1 - see PIRAMID Technical Reference Manual 4.x for failure probability estimation algorithms associated with each failure mechanism

Note 2 - Attribute Data Input Type:

S1 all consecutive sections delineated by KP start & KP end, defined by numeric value

S2 all consecutive sections delineated by KP start & KP end, defined by text string from predefined choice list

C1 continuously varying quantity defined by numeric values at KP reference locations

Table A.1 Line Attributes Affecting Probability of Failure

No.	Attribute Description	Attribute Name	Input Type[2]	Failure Consequence Model Affected[1]															
				Release Rate	Release Volume	Hazard Type	No. of Fatalities	Individ. Risk	Spill Volume	Clean-up Efficiency	Resid. Volume	Equiv. Volume	Repair Cost	Interrupt Time	Interrupt Cost	Product Cost	Clean-up Cost	Damage Cost	Total Cost
0	Product Type	Product		X	X	X	X		X	X	X	X			X	X	X	X	X
1	Pipe Diameter	PipeDia	S1	X	X		X		X		X	X	X	X	X	X	X	X	X
2	Pipe Wall Thickness	PipeWall	S1	X	X		X		X		X	X				X	X	X	X
3	Pipe Body Yield Strength	PipeYield	S1																
4	Pipe Body Seam Weld Type	SeamType	S2																
5	Pipe Joint Type	JointType	S2																
6	Line Age	LineAge	S1																
7	Line Elevation Profile	ElevProfile	C1	X	X		X		X		X	X				X	X	X	X
8	Operating Pressure Profile	PressProfile	C1	X	X		X		X		X	X				X	X	X	X
9	Operating Pressure Range	PressRange	S1																
10	Cumulative Number of Pressure Cycles	PressCycle	S1																
11	Operating Temperature	LineTemp	S1	X	X		X		X		X	X				X	X	X	X
12	Product Flow Rate (sign denotes flow direction)	FlowRate	S1	X	X		X		X		X	X			X	X	X	X	X
13	Line Volume (% of line capacity)	CapFraction	S1												X				X
14	Billing Abatement Threshold (% of nominated volume)	BAT	S1												X				X
15	Product Transportation Distance	TransDist	S1												X				X
16	Block Valve Spacing	ValveSpace	S1		X		X		X		X	X				X	X	X	X
17	Time to Block Valve Closure	TimeClose	S1		X		X		X		X	X				X	X	X	X
18	Detectable Release Volume	VolDetect	S1		X		X		X		X	X				X	X	X	X
19	Time to Leak Detection	TimeDetect	S1		X		X		X		X	X				X	X	X	X
20	Time to Leak Stoppage (from time of detection)	TimeStop	S1		X		X		X		X	X				X	X	X	X
21	Depth of cover	Cover	S1																
22	Adjacent Land Use	AdjLand	S2			X	X											X	X
23	ROW Accessibility	ROWaccess	S2										X	X	X				X
24	ROW Condition	ROWcond	S2																
25	ROW Patrol Frequency	ROWpatrol	S2																
26	Notification & Response System	Notify	S2																
27	Crossing Type / Special Terrain Features	Crossing	S2										X	X	X				X
28	Near Field Terrain Characteristics	NFTerrain	S2							X	X	X					X		X
29	General Soil Corrosivity	SoilCorrode	S2																
30	SCC Potential of Soil Environment	SCCPotential	S2																
31	External Pipe Coating Type	ExtCoating	S2																
32	External Pipe Coating Condition	CoatCond	S2																
33	Cathodic Protection Level	CPLevel	S2																
34	Presence of Coating Shielding	CoatShield	S2																
35	Presence of Electrical Interference or Casing Short	Interference	S2																
36	Product Corrosivity	ProdCorrode	S2																
37	Ground Movement Potential	GndMovPot	S2																
38	Pipe Fail Potential given Ground Movement	GndFailPot	S2																
39	Surface water within 300m	SrfWater	S2									X							
40	Drinking Water within 5 km	DrkWater	S2									X							
41	Other Water within 5 km	OthWater	S2									X							
42	Land Use within 5 km	DirExposure	S2									X							
43	Sensitive Environment within 10 km	SensEnviro	S2									X							
44	Sensitive Groundwater within 10 km	SensGndWtr	S2									X							

Note 1 - see PIRAMID Technical Reference Manual 3.x for failure consequence estimation algorithms
Note 2 - Attribute Data Input Type:
S1 all consecutive sections delineated by KP start & KP end, defined by numeric value
S2 all consecutive sections delineated by KP start & KP end, defined by text string from predefined choice list
C1 continuously varying quantity defined by numeric values at KP reference locations

Table A.2 Line Attributes Affecting Consequences of Failure

APPENDIX B

Description of Line Attributes for Offshore Pipelines (extract from PIRAMID™ Prioritization User's Guide – Appendix C)

Appendix B

The global system attributes that must be specified prior to describing individual pipelines within the system are defined as follows (see also Tables B.1 and B.2):

- **Spill Trajectory Launch Zones** A set of labels (*i.e.*, text strings) identifying distinct aerial extents of sea surface over which both the total probability of spill impact and the time to spill impact with susceptible coastal resources is constant.
- **Susceptible Coastal Resources** The set of coastal resources that could be impacted by a persistent liquid product spill, defined by name (*i.e.*, a user defined text string) and by association with predefined shoreline types.
- **Resource Impact Probability** The total probability of spill impact with each susceptible coastal resource for each spill trajectory launch zone.
- **Resource Impact Time** The probability distribution of the time to spill impact with each susceptible coastal resource for each spill trajectory launch zone.

The attributes that must be specified to fully define each pipeline are defined as follows (see also Tables B.1 and B.2):

- **Product Set** The list of products transported through the line segment and the relative amount of time that each product type is assumed to be in the line. Note that the specification of multiple product types is assumed to imply batched product shipping.
- **Pipe Diameter** The outside diameter of the line pipe.
- **Pipe Wall Thickness** The wall thickness of the line pipe.
- **Pipeline Orientation** The direction angle of a horizontal projection of the pipeline axis (defined as an azimuth angle from North). Note the direction of the pipeline axis is assumed to be in the direction of increasing KP distance (see Figure B.1).
- **Pipe Body Yield Strength** The specified yield strength of the line pipe steel.
- **Pipe Joint Type** The type of pipe joint (weld vs. mechanical joint) and a relative indication of joint quality for welded butt joints (*i.e.*, high quality, average quality, or poor quality). The characterization is intended to reflect the strength and ductility of the joint.
- **Line Age** The age of the line segment since initial construction.
- **Elevation Profile** The relative elevation (-ve values implying depth below sea level) of the line defined at the start and end points of the line and selected reference points along the length of the line. Note that the location of intermediate points should be chosen to adequately characterize the elevation profile given that the program uses linear interpolation to infer the elevation at all locations between specified reference points.
- **Pressure Profile** The anticipated maximum operating pressure in the line defined at the start and end points of the line and selected reference points along the length of the line. Note that the location of intermediate points should be chosen to adequately characterize the pressure profile given that the program uses linear interpolation to infer the line pressure at all locations between specified reference points. Note also that the specified pressure should reflect an upper bound pressure profile associated with likely worst case operating conditions including, for example, periodic line pack or shut in.
- **Operating Temperature** The average temperature of the product being transported through the line. Note that pipe body temperature is assumed to be equal to the product temperature.

- **Product Flow Rate** The product mass flow rate through the line segment under normal operating conditions. Note that a negative value implies a flow direction opposite to the direction of increasing KP distance (see Figure B.1).
- **Line Volume** The average nominated or tendered monthly flow volume, expressed as a percentage of pipeline through-put capacity.
- **Billing Abatement Threshold** The volume of product that must be delivered to avoid a service interruption cost penalty, expressed as a percentage of the nominated or tendered monthly volume.
- **Product Transport Distance** The total distance over which products traveling through the line segment are transported.
- **Block Valve Spacing** The spacing between isolation valves along the length of the line segment.
- **Time to Block Valve Closure** The time required to close the block valves measured from the time when the leak is first detected.
- **Detectable Release Volume** The maximum volume of product that can be lost from the line before leak detection equipment triggers a leak detection alarm. Note that it is assumed that steps will be taken to close all block valves immediately following the detection of a large leak or a rupture.
- **Time to Leak Detection** The time required to detect a small leak given that small leaks may only be detected by periodic line patrols or notification by third parties.
- **Time to Leak Stoppage** The time required by the operator to locate and repair a small leak measured from the time when the leak is first detected.
- **Spanning Stress Range** The longitudinal stress range associated with wave or current induced excitation of free spanning portions of the line. Note that complex stress vs. time loading histories must be characterized by a representative single value stress range and a cumulative number of stress cycles (see also Cumulative Number of Stress Cycles).
- **Cumulative Number of Stress Cycles** The effective number of longitudinal stress cycles experienced by the line since initial construction. Note that complex stress vs. time loading histories must be characterized by a representative single value stress range and a cumulative number of stress cycles (see also Spanning Stress Range).
- **Number of Free Spans** The number of pipeline free spans per unit line length.

Appendix B

- **Seabed Environment Corrosivity** A characterization of the relative degree to which the electrochemistry of the environment surrounding the pipe is conducive to promoting metal loss corrosion. The environment corrosivity categories are associated with distinct seabed soil types and pipe exposure conditions (see below).

Environment Corrosivity	Seabed Characterization
very low	Sand or Rock (low/medium organics)
low	Sand or Rock (high organics)e
moderate	Mud (low organics)
high	Mud (medium organics)
very high	Mud (high organics) / Exposed Pipe

- **SCC Potential of Soil Environment** A subjective characterization of the degree to which the environmental conditions surrounding the pipe are considered conducive to promoting stress corrosion cracking (*i.e.*, no potential, unlikely potential, likely potential, definite potential).
- **External Pipe Coating Type** The type of external coating applied to the pipeline (*i.e.*, polyethylene/epoxy, coal tar, asphalt, tape coat, none [bare pipe]).
- **External Pipe Coating Condition** A relative characterization of the integrity of the external coating compared to a typical instance of the selected coating type (*i.e.*, above average, average, below average).
- **Cathodic Protection Level** An estimate of the adequacy and uniformity of the voltage potential generated by the cathodic protection system. The cathodic protection level categories are associated with specific characterizations of voltage adequacy and uniformity (see below).

Cathodic Protection Level	Characterization
above average	adequate voltage, uniform level
average	adequate average voltage, some variability
below average	inadequate voltage and/or high variability
no cathodic protection	———

- **Product Corrosivity** A characterization of the relative corrosivity of the product set transported through the pipeline. The product corrosivity categories are associated with specific corrosion growth rate ranges (see below).

Product Corrosivity	Growth Rate (mm/yr)
negligible	< 0.02
low	0.02 to 0.1
moderate	0.1 to 0.5
high	0.5 to 2.5
extreme	> 2.5

- **Depth of Cover** The amount and uniformity of sediment cover on top of the pipeline (*i.e.*, none, intermittent or partial cover, or continuous significant cover).
- **Ground Movement Potential** An estimate of the frequency of occurrence of significant ground movement events on the right-of-way. The ground movement potential categories are associated with specific order-of-magnitude frequency values (see below).

Movement Potential	Frequency (events per km year)
Negligible	≤ 1 in 100,000
Low	1 in 10,000
Moderate	1 in 1000
High	1 in 100
Extreme	≥ 1 in 10

- **Pipe Damage Potential** An estimate of the likelihood of pipeline failure in the event of a significant ground movement event. The damage potential categories are associated with specific order-of-magnitude probability values (see below).

Damage Potential	Failure Probability (per movement event)
Low	≤ 1 in 100
Moderate	1 in 10
High	1 in 1

- **Adjacent Platform Type / Offset** The type (*i.e.*, major manned, minor manned, major unmanned, or minor unmanned) and location (*i.e.*, reference kilometer post) of permanent offshore facilities adjacent to the pipeline, and the perpendicular offset distance (*i.e.*, the 'y' coordinate distance, see Figure B.1 for sign convention) from a point on the sea surface directly above the line to the centre of each designated facility.

Appendix B

- **Vessel Traffic Density** The category of vessel traffic density (*i.e.*, high density, medium density, low density, or no significant traffic) on the sea surface above the pipeline. The traffic density categories are associated with specific types and levels of sea surface use (see below).

Vessel Traffic density	Growth Rate (mm/yr)
No Significant Traffic	No prescribed use
Low traffic Density	Very light traffic or designated fishing area
Moderate Traffic Density	Low to moderate volume shipping corridor
High Traffic Density	High Volume shipping corridor

- **Subsea Activity** An indication of whether surface vessel traffic is associated with significant subsea activity (*i.e.*, no designated activity, or designated fishing or anchoring zone).
- **Spill Trajectory Launch Zone** An identifier (*i.e.*, a text string label) delineating the extent of pipeline along which it is assumed that both the probability of shoreline impact and the time to impact of potential product spills are essentially constant.

The sign convention employed for attribute specification is shown in Figure B.1.

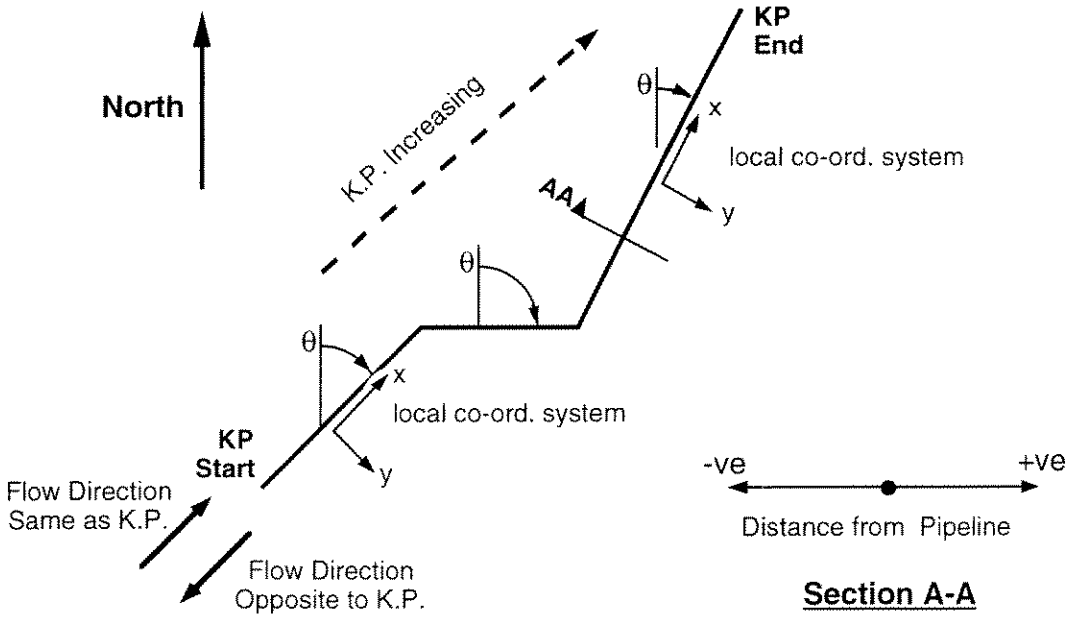


Figure B.1 Pipeline attribute sign convention

Appendix B

No.	Attribute Description	Attribute Name	Input Type[2]	Failure Mechanism Affected[1]							
				External Corrosion	Internal Corrosion	Mechanical Damage	Nat. Hazard Damage	Ground Movement	Cracking (SCC)	Cracking (weld fatigue)	Other Causes
0	Product Type	Product									
1	Pipe Diameter	PipeDia	S1	X	X	X	X		X		X
2	Pipe Wall Thickness	PipeWall	S1						X		
3	Pipe Body Yield Strength	PipeYield	S1						X		
4	Pipe Joint Type	JointType	S2					X		X	
5	Line Age	LineAge	S1	X	X				X		
6	Pipe Orientation	Orient	S1								
7	Elevation/Depth Profile (-ve implies depth)	ElevProfile	C1								
8	Pressure Profile	PressProfile	C1						X		
9	Longitudinal Stress Range	StressRange	S1							X	
10	Cumulative Number of Stress Cycles	StressCycle	S1							X	
11	Number of Free Spans	Nspan	S1							X	
12	Operating Temperature	LineTemp	S1	X					X		
13	Product Flow Rate (sign denotes flow direction)	FlowRate	S1								
14	Line Volume (% of line capacity)	CapFraction	S1								
15	Billing Abatement Threshold (% of nominated volume)	BAT	S1								
16	Product Transportation Distance	TransDist	S1								
17	Block Valve Spacing	ValveSpace	S1								
18	Time to Block Valve Closure	TimeClose	S1								
19	Detectable Release Volume	VolDetect	S1								
20	Time to Leak Detection	TimeDetect	S1								
21	Time to Leak Stoppage (from time of detection)	TimeStop	S1								
22	Depth of Cover	Cover	S2			X	X				
23	Vessel Traffic Density	VesselDens	S2			X	X				
24	Subsea Activity	SubSeaAct	S2			X	X				
25	Seabed Environment Corrosivity	EnvCorrode	S2	X					X		
26	SCC Potential of Seabed Environment	SCCPotential	S2						X		
27	External Pipe Coating Type	ExtCoating	S2	X					X		
28	External Pipe Coating Condition	CoatCond	S2	X					X		
29	Cathodic Protection Level	CPLevel	S2	X					X		
30	Product Corrosivity	ProdCorrode	S2		X						
31	Ground Movement Potential	GndMovPot	S2					X			
32	Pipe Fail Potential given Ground Movement	GndFailPot	S2					X			
33a	Adjacent Platform - type	PlatType	P1								
33b	Adjacent Platform - offset	PlatOffset	P1								
34	Spill Trajectory Launch Zone	LaunchZone	S3								
35	Susceptible Coastal Resources / Shoreline Types	Reource	S4								
36	Coastal Resource Impact Probability	ImpactTime	S5								
37	Coastal Resource Impact Time	ImpactProb	S5								
38	*Water Depth Range (calc. from Elevation Profile)*	*DepthRange*	*S2*			*X*	*X*				

Note 1 - see PIRAMID Technical Reference Manual 7.x for failure probability estimation algorithms associated with each failure mechanism

Note 2 - Attribute Data Input Type:

S1 all consecutive sections delineated by KP start & KP end, defined by numeric value

S2 all consecutive sections delineated by KP start & KP end, defined by text string from predefined choice list

S3 all consecutive sections delineated by KP start & KP end, defined by user defined text string

S4 all possible locations defined by a text string label and referenced to a predefined list of shoreline types

S5 all possible locations defined by numeric value

P1 selected locations defined by: a) a text string from a predefined choice list and b) a numeric value

C1 continuously varying quantity defined by numeric values at KP reference locations

Table B.1 Line Attributes Affecting Probability of Failure

No.	Attribute Description	Attribute Name	Input Type[2]	Failure Consequence Model Affected[1]																
				Release Rate	Release Volume	Hazard Type	No. of Fatalities	Spill Volume	Impact Location	Impact Time	Impact Volume	Resid. Volume	Equiv. Volume	Repair Cost	Interrupt Time	Interrupt Cost	Product Cost	Offshore Cl'n Cost	Onshore Cl'n Cost	Offshore Dmg Cost	Onshore Dmg Cost	Total Cost
0	Product Type	Product		X	X	X	X	X			X	X	X			X	X	X	X	X	X	X
1	Pipe Diameter	PipeDia	S1	X	X		X	X			X	X	X	X	X	X	X	X	X	X	X	X
2	Pipe Wall Thickness	PipeWall	S1	X	X		X	X			X	X	X				X	X	X	X	X	X
3	Pipe Body Yield Strength	PipeYield	S1																			
4	Pipe Joint Type	JointType	S2																			
5	Line Age	LineAge	S1																			
6	Pipe Orientation	Orient	S1				X													X		X
7	Elevation/Depth Profile (-ve implies depth)	ElevProfile	C1	X	X		X	X			X	X	X				X	X	X	X	X	X
8	Pressure Profile	PressProfile	C1	X	X		X	X			X	X	X				X	X	X	X	X	X
9	Longitudinal Stress Range	StressRange	S1																			
10	Cumulative Number of Stress Cycles	StressCycle	S1																			
11	Number of Free Spans	Nspan	S1																			
12	Operating Temperature	LineTemp	S1	X	X		X	X			X	X	X				X	X	X	X	X	X
13	Product Flow Rate (sign denotes flow direction)	FlowRate	S1	X	X		X	X			X	X	X			X	X	X	X	X	X	X
14	Line Volume (% of line capacity)	CapFraction	S1													X						X
15	Billing Abatement Threshold (% of nominated volume)	BAT	S1													X						X
16	Product Transportation Distance	TransDist	S1													X						X
17	Block Valve Spacing	ValveSpace	S1		X		X	X			X	X	X				X	X	X	X	X	X
18	Time to Block Valve Closure	TimeClose	S1		X		X	X			X	X	X				X	X	X	X	X	X
19	Detectable Release Volume	VolDetect	S1		X		X	X			X	X	X				X	X	X	X	X	X
20	Time to Leak Detection	TimeDetect	S1		X		X	X			X	X	X				X	X	X	X	X	X
21	Time to Leak Stoppage (from time of detection)	TimeStop	S1		X		X	X			X	X	X				X	X	X	X	X	X
22	Depth of Cover	Cover	S2				X											X		X		X
23	Vessel Traffic Density	VesselDens	S2			X	X													X		X
24	Subsea Activity	SubSeaAct	S2																			
25	Seabed Environment Corrosivity	EnvCorrode	S2																			
26	SCC Potential of Seabed Environment	SCCPotentia	S2																			
27	External Pipe Coating Type	ExtCoating	S2																			
28	External Pipe Coating Condition	CoatCond	S2																			
29	Cathodic Protection Level	CPLevel	S2																			
30	Product Corrosivity	ProdCorrode	S2																			
31	Ground Movement Potential	GndMovPot	S2																			
32	Pipe Fail Potential given Ground Movement	GndFailPot	S2																			
33a	Adjacent Platform - type	PlatType	P1				X													X		X
33b	Adjacent Platform - offset	PlatOffset	P1				X													X		X
34	Spill Trajectory Launch Zone	LaunchZone	S3						X	X	X	X	X						X		X	X
35	Susceptible Coastal Resources / Shoreline Types	Reource	S4						X	X	X	X	X						X		X	X
36	Coastal Resource Impact Probability	ImpactTime	S5						X		X	X	X						X		X	X
37	Coastal Resource Impact Time	ImpactProb	S5							X	X	X	X						X		X	X
38	*Water Depth Range (calc. from Elevation Profile)*	*DepthRange*	*S2*											X	X	X						X

Note 1 - see PIRAMID Technical Reference Manual 7.x for failure probability estimation algorithms associated with each failure mechanism

Note 2 - Attribute Data Input Type:

S1 all consecutive sections delineated by KP start & KP end, defined by numeric value

S2 all consecutive sections delineated by KP start & KP end, defined by text string from predefined choice list

S3 all consecutive sections delineated by KP start & KP end, defined by user defined text string

S4 all possible locations defined by a text string label and referenced to a predefined list of shoreline types

S5 all possible locations defined by numeric value

P1 selected locations defined by: a) a text string from a predefined choice list and b) a numeric value

C1 continuously varying quantity defined by numeric values at KP reference locations

Table B.2 Line Attributes Affecting Consequences of Failure

APPENDIX C

Workshop Presentation Material – Onshore Pipeline Systems

Section A

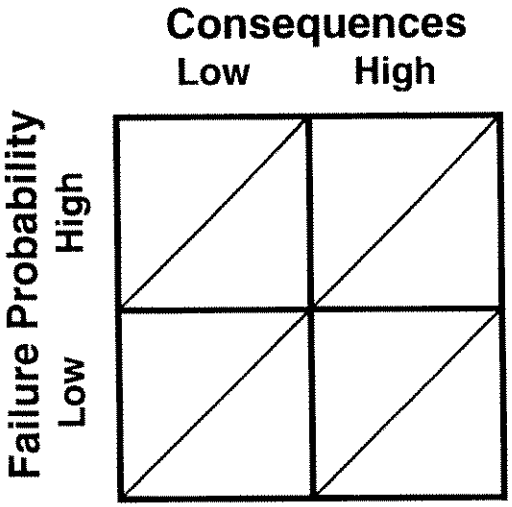
Overview

Validation of *PIRAMID* Prioritization

- **Objectives**
  - Analyze representative pipeline segments
  - Assess degree to which results are consistent with
    - » historical trends
    - » engineering judgement
  - Identify areas for improvement
    - » repeatability of results
      - reduce ambiguity associated with input data
    - » accuracy of results
      - improve accuracy of physical and/or probabilistic models
- **Outcome**
  - Enhanced user confidence
  - Provide input into the planned software updating project

Test Cases - requested

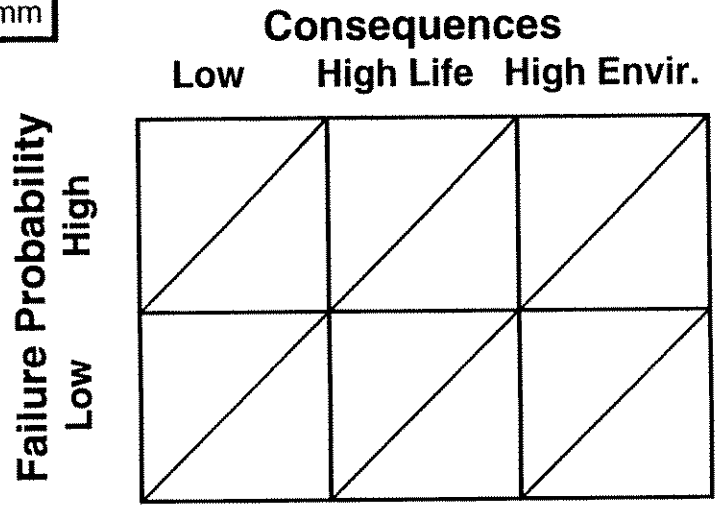
Gas Pipelines



Small 300mm

Large 900mm

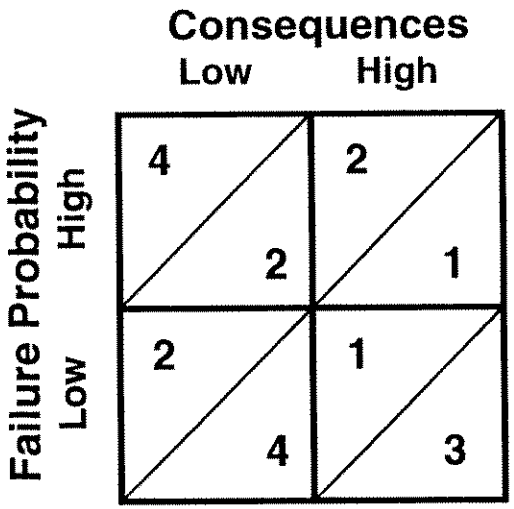
Liquid Pipelines



Test Cases - received

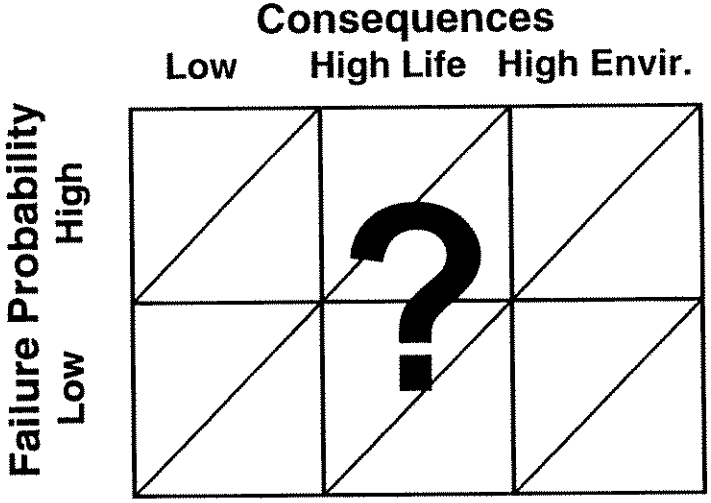
On Shore Pipelines

Gas Pipelines
(BC Gas, BG, Nova, TCPL)



9 Small Dia. (273 - 457mm)
10 Large Dia. (914 - 1067mm)

Liquid Pipelines
(IPL, Trans Mountain)



Not participating:
Foothills, GSC, GRI

Label	Operator	Segment Name	Dia.	Land Use	Probability	Consequence	Comment
A1			324	Res Urb	H	H	Probability and Conseq. Ranking Assigned by CFER
A2			324	Res Rur	H	L	
A3			324	Res Urb	L	H	
A4			324	Rem Oth	L	L	
B1			914	Res Urb	M	H	
B2			914	Rem For	H	L	
B3			914	Rem For	L	L	
B4			1067	Prk For	L	M	
C1			914	Agr	L	L	Probability and Conseq. Ranking Assigned by CFER
C2			914	Res Urb/Rur	L	HJ	
C3			300	Ind	H	L	
D1			914	Res Urb	L	H	
D2			914	Rem For	L-M	L	
D3			324	Prk For	M	L	
D4			457	Prk For	H	L	
D5			406	Agr	L-M	L	
D6			273	Res Urb	M	H	
D7			914	Prk Oth	L	L	
D8			914	Agr	L-M	L	

Results Obtained - onshore gas lines

Pipeline section ranking by

- **Probability of failure** (incidents / km*yr)

- **Expected Cost** ($ / km*yr)
  - » probability of failure x financial cost given failure

- **Expected No. of Fatalities** (per km*yr)
  - » probability of failure x fatalities given failure

- **Total Risk** ($ / km*yr)
  - » expected cost + (expected fatalities x λ)
    - λ is the "societal value of a human life"

Section B

Line Attributes and Attribute Definitions for On Shore Gas Pipelines

No.	Attribute Description	Attribute Name	Units ext (int)	Input Type	Required for Probability Estimation	Required for Consequence Estimation	Analysis Preferences			
							Natural Gas only	HVP liquids only	LVP liquids included	
									consider env.	suppress env.
1	Pipe Diameter	PipeDia	mm (m)	S1	X	X	X	X	X	X
2	Pipe Wall Thickness	PipeWall	mm (m)	S1	X	X	X	X	X	X
3	Pipe Body Yield Strength	PipeYield	MPa (Pa)	S1	X		X	X	X	X
4	Pipe Body Seam Weld Type	SeamType		S2	X		X	X	X	X
5	Pipe Joint Type	JointType		S2	X		X	X	X	X
6	Line Age	LineAge	years	S1	X		X	X	X	X
7	Line Elevation Profile	ElevProfile	m	C1		X		X	X	X
8	Operating Pressure Profile	PressProfile	kPa (Pa)	C1	X	X	X	X	X	X
9	Operating Pressure Range	PressRange	kPa (Pa)	S1	X		X	X	X	X
10	Cumulative Number of Pressure Cycles	PressCycle		S1	X		X	X	X	X
11	Operating Temperature	LineTemp	°C (K)	S1	X	X	X	X	X	X
12	Product Flow Rate (sign denotes flow direction)	FlowRate	kg/s	S1		X	X	X	X	X
13	Line Volume (percentage of line capacity)	CapFraction	% (fraction)	S1		X	X	X	X	X
14	Billing Abatement Threshold (percentage of nominated volume	BAT	% (fraction	S1		X	X	X	X	X
15	Product Transportation Distance	TransDist	km (m)	S1		X	X	X	X	X
16	Block Valve Spacing	ValveSpace	km (m)	S1		X	X	X	X	X
17	Time to Block Valve Closure	TimeClose	min (sec)	S1		X	X	X	X	X
18	Detectable Release Volume	VolDetect	cu. m.	S1		X	X	X	X	X
19	Time to Leak Detection	TimeDetect	hrs (sec)	S1		X	X	X	X	X
20	Time to Leak Stoppage (from time of detection)	TimeStop	hrs (sec)	S1		X	X	X	X	X
21	Depth of cover	Cover	m	S1	X		X	X	X	X
22	Adacent Land Use	AdjLand		S2	X	X	X	X	X	X
23	ROW Accessibility	ROWaccess		S2		X	X	X	X	X
24	ROW Condition	ROWcond		S2	X		X	X	X	X
25	ROW Patrol Frequency	ROWpatrol		S2	X		X	X	X	X
26	Notification & Response System	Notify		S2	X		X	X	X	X
27	Crossing Type / Special Terrain Features	Crossing		S2	X				X	
28	Near Field Terrain Characteristics	NFTerrain		S2		X			X	
29	General Soil Corrosivity	SoilCorrode		S2	X		X	X	X	X
30	SCC Potential of Soil Environment	SCCPotential		S2	X		X	X	X	X
31	External Pipe Coating Type	ExtCoating		S2	X		X	X	X	X
32	External Pipe Coating Condition	CoatCond		S2	X		X	X	X	X
33	Cathodic Protection Level	CPLevel		S2	X		X	X	X	X
34	Presence of Coating Shielding	CoatShield		S2	X		X	X	X	X
35	Presence of Electrical Interference or Casing Short	Interference		S2	X		X	X	X	X
36	Product Corrosivity	ProdCorrode		S2	X		X	X	X	X
37	Ground Movement Potential	GndMovPot		S2	X		X	X	X	X
38	Pipe Fail Potential given Ground Movement	GndFailPot		S2					X	
39	Surface water within 300m	SrfWater		S2		X			X	
40	Drinking Water within 5 km	DrkWater		S2		X			X	
41	Other Water within 5 km	OthWater		S2		X			X	
42	Land Use within 5 km	DirExposure		S2		X			X	
43	Sensitive Environment within 10 km	SensEnviro		S2		X			X	
44	Sensitive Groundwater within 10 km	SensGndWtr		S2		X			X	

Attribute Data Input Type

S1 all consecutive sections delineated by KP start & KP end, defined by numeric value

S2 all consecutive sections delineated by KP start & KP end, defined by text string from predefined choice list

C1 continuously varying quantity defined by numeric values at KP reference locations

Pipeline segment attributes for prioritization

External Metal Loss Corrosion - Subjective Attribute Characterization

Soil Corrosivity	Resistivity (ohm•cm)	Soil Characterization: Drainage / Texture
low	> 10,000	excessively drained - coarse texture
below average	5000 - 10,000	well drained - moderately coarse texture, or poorly drained - coarse texture
average	2000 - 5000	well drained - moderately fine texture, or poorly drained - moderately coarse texture, or very poorly drained with high steady water table
above average	1000 - 2000	well drained - fine texture, or poorly drained - moderately fine texture, or very poorly drained with fluctuating water table
high	< 1000	poorly drained - fine texture, or mucks, peats with fluctuating water table

Cathodic Protection Level	Characterization
above average	adequate* voltage, uniform level
average	adequate* average voltage, some variability
below average	inadequate* voltage and/or high variability
no cathodic protection	———

* Note: adequate voltage assumed to fall within a -850 to -1170 mV Instant OFF range.

Coating Condition	Characterization
above average	Coating condition to be assessed relative to the
average	assumed average condition of the coating type
below average	given its age and operating temperature

Internal Metal Loss Corrosion - Subjective Attributes

Product Corrosivity	Estimated Feature Depth Growth Rate (mm/yr)
negligible	< 0.02
low	0.02 to 0.1
moderate	0.1 to 0.5
high	0.5 to 2.5
extreme	> 2.5

Mechanical Damage - Subjective Attributes

Right-of-way Condition	Characterization
Excellent	Highly distinctive Right-of-way highly visible signage
Above average	
Average	Limited or variable indication of Right-of-way signage at selected strategic locations
Below average	
Poor	Indistinct Right-of-way no signage

Dig Notification / Response System	Characterization
One-call system (high awareness level)	Note: awareness level defined subjectively
One-call system (average awareness level)	to reflect the degree to which public and
One-call system (low awareness level)	contractors are made aware of pipeline
None	and availability of one-call response

Ground Movement - Subjective Attribute

Ground Movement Potential	Characterization (estimated likelihood of movement event per km yr)
Negligible	(≤ 1 in 100,000)
Low	(1 in 10,000)
Moderate	(1 in 1000)
High	(1 in 100)
Extreme	(≥ 1 in 10)

Pipe Failure Potential	Characterization (failure potential given movement event)
Low	(≤ 1 in 100)
Moderate	(1 in 10)
High	(1 in 1)

Joint Type	Characterization
High quality weld	Note: weld quality estimate established subjectively based on perceived level of quality control associated with the making and inspecting of butt welds
Average quality weld	
Poor quality weld	
Mechanical joint	

Environmentally Induced Crack-Like Defects (SCC) - Subjective Attributes

SCC Potential	Characterization
no potential	SCC potential tied to rating obtained
unlikely potential	from SCC soil susceptibility model
likely potential	Note: this input is assumed to come
definite potential	from company specific models

Cathodic Protection Level	Characterization
above average	adequate* voltage, uniform level
average	adequate* average voltage, some variability
below average	inadequate* voltage and/or high variability
no cathodic protection	

* Note: adequate voltage assumed to fall within a -850 to -1170 mV Instant OFF range.

Mechanically Induced Crack-Like Defects (metal fatigue) - Subjective Attributes

Seam Weld Type	Characterization
None (seamless)	
High quality weld	
Suspect weld	Problematic vintages of ERW or SAW welds
Poor quality weld	e.g. butt welded seams

Section C

Model Input Data for On Shore Gas Pipelines

PIRAMID Onshore Prioritization Version 1.5
Model: D:\PIPELINE TECH JIP\Risk-Based Optimization\97 Program\Verification\Model Files\FinalC

Onshore

MODEL SUMMARY REPORT started Fri Apr 17 14:58:34 1998

##
tem Data

System Title: Onshore Verification Model (with serv. int.)
Analysis Date: March 1998
Analysis Preferences: Natural Gas (without Environmental assessment)

Baseline Failure Rates:

Failure Cause	Reference Segment Failure Rate (Incidents per km*yr)	Relative Failure Probability Small Leak	Large Leak	Rupture
External Corrosion	0.0003000	0.85	0.10	0.05
Internal Corrosion	0.0000500	0.85	0.10	0.05
Mechanical Damage	0.0003000	0.25	0.50	0.25
Ground Movement	N/A	0.20	0.40	0.40
Stress Corrosion Cracking	N/A	0.60	0.30	0.10
Seam Weld Fatigue	N/A	0.60	0.30	0.10
Other	0.0002000	0.80	0.10	0.10

Failure Cause	Reference Segment Scale Factor (Kxx)
External Corrosion	1.69e-05
Internal Corrosion	0.153
Mechanical Damage	61.7
Ground Movement	N/A
Stress Corrosion Cracking	N/A
m Weld Fatigue	N/A
er	N/A

##
Segment Data

Total Number of Distinct Segments: 19

****
* Pipe Segment #1: [redacted] A1
* Total Length : 10 km (0 km to 10 km)
* Product Type(s): Methane(100%)
****

Section #1: 0km to 10km

Attribute	Value
Pipeline Diameter	323.9 mm
Pipe Wall Thickness	5.16 mm
Pipe Body Yield Strength	290 MPa
Pipe Body Seam Weld Type	High Quality Weld
Pipe Joint Type	Average Quality Weld
Line Age	41 years
Elevation Profile	N/A
Pressure Profile	5000 kPa
Operating Pressure Range	500 kPa
Cumulative Number of Pressure Cycles	10000 cycles
Operating Temperature	20 °C
duct Flow Rate	10 kg/s
e Volume	100 %
Billing Abatement Threshold	100 %
Product Transportation Distance	0 km
Block Valve Spacing	12.8 km

Time to Block Valve Closure	60 min
Detectable Release Volume	2000 m³
Time to Leak Detection	84 hr
Time to Leak Stoppage	24 hr
Depth of Cover	1.5 m
Adjacent Land Use	Residential - Urban
Accessibility	Near (easy access)
Condition	Below Average
ROW Patrol Frequency	Monthly
Notification & Response System	System (limited awareness)
Crossings/Special Terrain	Typical X-Country Conditions
Near Field Terrain	N/A
General Soil Corrosivity	Average (2000 - 5000 ohm*cm)
SCC Potential of Soil Environment	Likely Potential
External Pipe Coating Type	Tape
External Pipe Coating Condition	Below Average
Cathodic Protection Level	Average
Presence of Coating Shielding	No
Electrical Interference/Casing Short	No
Product Corrosivity	Negligible (< 0.02 mm/yr)
Ground Movement Potential	Negligible (<= 1 in 100,000/km)
Pipe Damage Potential	Low (<= 1 in 100)
Surface Water within 300 m	N/A
Drinking Water within 5 km	N/A
Other Water within 5 km	N/A
Land Use within 5 km	N/A
Sensitive Environment within 10 km	N/A
Sensitive Groundwater within 10 km	N/A

Elevation Profile

kilometre post	line elevation (m)
N/A	N/A

Pressure Profile

kilometre post	operating pressure (kPa)
	5000
	5000

---------- Probability and Consequence Estimates ----------

Segment: [redacted] A1

Section #1: 0 km to 10 km

Failure Cause	Failure Probability (incidents/year) Small Leak	Large Leak	Rupture
External Corrosion	0.0108226	0.0012733	0.0006366
Internal Corrosion	0.0000207	0.0000024	0.0000012
Mechanical Damage	0.0034698	0.0069395	0.0034698
Ground Movement	0.0000002	0.0000004	0.0000004
Stress Corrosion Cracking	0.0019099	0.0009549	0.0003183
Seam Weld Fatigue	0.0000000	0.0000000	0.0000000
Other	0.0016000	0.0002000	0.0002000
Cost of Failure ($ per incident)	$92488	$2815380	$63192800

****

* Pipe Segment #2: [redacted] A2

* Total Length : 10 km (0 km to 10 km)

* Product Type(s): Methane(100%)

****

Section #1: 0km to 10km

Attribute	Value
Pipeline Diameter	323.9 mm
Pipe Wall Thickness	5.16 mm
Pipe Body Yield Strength	290 MPa
Pipe Body Seam Weld Type	Suspect Weld
Pipe Joint Type	Average Quality Weld

Line Age	41 years
Elevation Profile	N/A
Pressure Profile	5000 kPa
Operating Pressure Range	500 kPa
Cumulative Number of Pressure Cycles	10000 cycles
Operating Temperature	20 °C
oduct Flow Rate	10 kg/s
ne Volume	100 %
Billing Abatement Threshold	100 %
Product Transportation Distance	0 km
Block Valve Spacing	12.8 km
Time to Block Valve Closure	60 min
Detectable Release Volume	2000 m³
Time to Leak Detection	84 hr
Time to Leak Stoppage	24 hr
Depth of Cover	1.1 m
Adjacent Land Use	Residential - Rural
ROW Accessibility	Far (difficult access)
ROW Condition	Poor
ROW Patrol Frequency	Monthly
Notification & Response System	System (limited awareness)
Crossings/Special Terrain	Bog/Muskeg
Near Field Terrain	N/A
General Soil Corrosivity	Above Average (1000 - 2000 ohm*cm)
SCC Potential of Soil Environment	Likely Potential
External Pipe Coating Type	Tape
External Pipe Coating Condition	Below Average
Cathodic Protection Level	Average
Presence of Coating Shielding	No
Electrical Interference/Casing Short	No
Product Corrosivity	Negligible (< 0.02 mm/yr)
Ground Movement Potential	Negligible (<= 1 in 100,000/km)
Pipe Damage Potential	Low (<= 1 in 100)
Surface Water within 300 m	N/A
Drinking Water within 5 km	N/A
her Water within 5 km	N/A
nd Use within 5 km	N/A
Sensitive Environment within 10 km	N/A
Sensitive Groundwater within 10 km	N/A

Elevation Profile

kilometre post	line elevation (m)
N/A	N/A

Pressure Profile

kilometre post	operating pressure (kPa)
0	5000
10	5000

---------- Probability and Consequence Estimates ----------

Segment: [redacted] A2

Section #1: 0 km to 10 km

Failure Cause	Failure Probability (incidents/year) Small Leak	Large Leak	Rupture
External Corrosion	0.0248920	0.0029285	0.0014642
Internal Corrosion	0.0000207	0.0000024	0.0000012
Mechanical Damage	0.0003616	0.0007231	0.0003616
Ground Movement	0.0000002	0.0000004	0.0000004
Stress Corrosion Cracking	0.0043927	0.0021964	0.0007321
Seam Weld Fatigue	0.0000000	0.0000000	0.0000000
Other	0.0016000	0.0002000	0.0002000
st of Failure ($ per incident)	$19481	$259214	$1371880

****

* Pipe Segment #3: [redacted] A3

* Total Length : 10 km (0 km to 10 km)

* Product Type(s): Methane(100%)

****

Section #1: 0km to 10km

Attribute	Value
Pipeline Diameter	323.9 mm
Pipe Wall Thickness	5.16 mm
Pipe Body Yield Strength	290 MPa
Pipe Body Seam Weld Type	High Quality Weld
Pipe Joint Type	Average Quality Weld
Line Age	41 years
Elevation Profile	N/A
Pressure Profile	5000 kPa
Operating Pressure Range	500 kPa
Cumulative Number of Pressure Cycles	10000 cycles
Operating Temperature	20 °C
Product Flow Rate	17 kg/s
Line Volume	100 %
Billing Abatement Threshold	100 %
Product Transportation Distance	2438 km
Block Valve Spacing	12 km
Time to Block Valve Closure	90 min
Detectable Release Volume	2000 m³
Time to Leak Detection	84 hr
Time to Leak Stoppage	24 hr
Depth of Cover	1.65 m
Adjacent Land Use	Residential - Urban
ROW Accessibility	Near (easy access)
ROW Condition	Average
ROW Patrol Frequency	Monthly
Notification & Response System	System (limited awareness)
Crossings/Special Terrain	Typical X-Country Conditions
Near Field Terrain	N/A
General Soil Corrosivity	Below Average (5000 - 10,000 ohm*cm)
°C Potential of Soil Environment	Unlikely Potential
External Pipe Coating Type	Asphalt
External Pipe Coating Condition	Average
Cathodic Protection Level	Below Average
Presence of Coating Shielding	No
Electrical Interference/Casing Short	No
Product Corrosivity	Negligible (< 0.02 mm/yr)
Ground Movement Potential	Low (1 in 10,000/km)
Pipe Damage Potential	Low (<= 1 in 100)
Surface Water within 300 m	N/A
Drinking Water within 5 km	N/A
Other Water within 5 km	N/A
Land Use within 5 km	N/A
Sensitive Environment within 10 km	N/A
Sensitive Groundwater within 10 km	N/A

Elevation Profile

kilometre post	line elevation (m)
N/A	N/A

Pressure Profile

kilometre post	operating pressure (kPa)
0	5000
10	5000

---------- Probability and Consequence Estimates ----------

Segment: [redacted] A3

Section #1: 0 km to 10 km

Failure Cause	Failure Probability (incidents/year) Small Leak	Large Leak	Rupture
External Corrosion	0.0054384	0.0006398	0.0003199
Internal Corrosion	0.0000207	0.0000024	0.0000012

Mechanical Damage	0.0017177	0.0034354	0.0017177
Ground Movement	0.0000020	0.0000040	0.0000040
Stress Corrosion Cracking	0.0001919	0.0000960	0.0000320
Seam Weld Fatigue	0.0000000	0.0000000	0.0000000
Other	0.0016000	0.0002000	0.0002000
st of Failure ($ per incident)	$95908	$2896460	$63313100

****

* Pipe Segment #4: [redacted] A4
* Total Length : 10 km (0 km to 10 km)
* Product Type(s): Methane(100%)

****

Section #1: 0km to 10km

Attribute	Value
Pipeline Diameter	323.9 mm
Pipe Wall Thickness	5.16 mm
Pipe Body Yield Strength	290 MPa
Pipe Body Seam Weld Type	High Quality Weld
Pipe Joint Type	Average Quality Weld
Line Age	41 years
Elevation Profile	N/A
Pressure Profile	5000 kPa
Operating Pressure Range	500 kPa
Cumulative Number of Pressure Cycles	10000 cycles
Operating Temperature	20 °C
Product Flow Rate	10 kg/s
Line Volume	100 %
Billing Abatement Threshold	100 %
Product Transportation Distance	0 km
Block Valve Spacing	24.6 km
Time to Block Valve Closure	60 min
Detectable Release Volume	2000 m³
me to Leak Detection	84 hr
me to Leak Stoppage	24 hr
Depth of Cover	0.6 m
Adjacent Land Use	Remote - other
ROW Accessibility	Near (easy access)
ROW Condition	Average
ROW Patrol Frequency	Monthly
Notification & Response System	System (limited awareness)
Crossings/Special Terrain	Typical X-Country Conditions
Near Field Terrain	N/A
General Soil Corrosivity	Average (2000 - 5000 ohm*cm)
SCC Potential of Soil Environment	Unlikely Potential
External Pipe Coating Type	Asphalt
External Pipe Coating Condition	Average
Cathodic Protection Level	Average
Presence of Coating Shielding	No
Electrical Interference/Casing Short	No
Product Corrosivity	Negligible (< 0.02 mm/yr)
Ground Movement Potential	Moderate (1 in 1000/km)
Pipe Damage Potential	Moderate (1 in 10)
Surface Water within 300 m	N/A
Drinking Water within 5 km	N/A
Other Water within 5 km	N/A
Land Use within 5 km	N/A
Sensitive Environment within 10 km	N/A
Sensitive Groundwater within 10 km	N/A

Elevation Profile

kilometre post	line elevation (m)
A	N/A

Pressure Profile

kilometre post	operating pressure (kPa)
0	5000

10 5000

---------- Probability and Consequence Estimates ----------
Segment: [redacted] 94
Section #1: 0 km to 10 km

Failure Cause	Failure Probability (incidents/year) Small Leak	Large Leak	Rupture
External Corrosion	0.0027056	0.0003183	0.0001592
Internal Corrosion	0.0000207	0.0000024	0.0000012
Mechanical Damage	0.0001299	0.0002598	0.0001299
Ground Movement	0.0002000	0.0004000	0.0004000
Stress Corrosion Cracking	0.0000955	0.0000477	0.0000159
Seam Weld Fatigue	0.0000000	0.0000000	0.0000000
Other	0.0016000	0.0002000	0.0002000
Cost of Failure ($ per incident)	$18441	$213316	$208496

****
* Pipe Segment #5: [redacted] 81
* Total Length : 10 km (0 km to 10 km)
* Product Type(s): Methane(100%)
****

Section #1: 0km to 10km

Attribute	Value
Pipeline Diameter	914 mm
Pipe Wall Thickness	14.07 mm
Pipe Body Yield Strength	448 MPa
Pipe Body Seam Weld Type	High Quality Weld
Pipe Joint Type	Average Quality Weld
Line Age	21 years
Elevation Profile	N/A
~essure Profile	6445 kPa
~erating Pressure Range	500 kPa
~umulative Number of Pressure Cycles	2100 cycles
Operating Temperature	21.83 °C
Product Flow Rate	206.308 kg/s
Line Volume	100 %
Billing Abatement Threshold	90 %
Product Transportation Distance	3000 km
Block Valve Spacing	27.861 km
Time to Block Valve Closure	15 min
Detectable Release Volume	2000 m³
Time to Leak Detection	84 hr
Time to Leak Stoppage	24 hr
Depth of Cover	1 m
Adjacent Land Use	Residential - Urban
ROW Accessibility	Near (easy access)
ROW Condition	Average
ROW Patrol Frequency	Weekly
Notification & Response System	System (limited awareness)
Crossings/Special Terrain	Typical X-Country Conditions
Near Field Terrain	N/A
General Soil Corrosivity	Average (2000 - 5000 ohm*cm)
SCC Potential of Soil Environment	Unlikely Potential
External Pipe Coating Type	Coal Tar
External Pipe Coating Condition	Average
Cathodic Protection Level	Below Average
Presence of Coating Shielding	No
Electrical Interference/Casing Short	No
Product Corrosivity	Negligible (< 0.02 mm/yr)
~ound Movement Potential	Negligible (<= 1 in 100,000/km)
~e Damage Potential	Moderate (1 in 10)
Surface Water within 300 m	N/A
Drinking Water within 5 km	N/A
Other Water within 5 km	N/A

Land Use within 5 km	N/A
Sensitive Environment within 10 km	N/A
Sensitive Groundwater within 10 km	N/A

Elevation Profile

kilometre post	line elevation (m)
0	N/A

Pressure Profile

kilometre post	operating pressure (kPa)
0	6445
10	6445

---------- Probability and Consequence Estimates ----------

Segment: [redacted] B1

Section #1: 0 km to 10 km

Failure Cause	Failure Probability (incidents/year) Small Leak	Large Leak	Rupture
External Corrosion	0.0008491	0.0000999	0.0000499
Internal Corrosion	0.0000039	0.0000005	0.0000002
Mechanical Damage	0.0000002	0.0000005	0.0000002
Ground Movement	0.0000020	0.0000040	0.0000040
Stress Corrosion Cracking	0.0000000	0.0000000	0.0000000
Seam Weld Fatigue	0.0000000	0.0000000	0.0000000
Other	0.0016000	0.0002000	0.0002000
Cost of Failure ($ per incident)	$115774	$3655140	$693967000

****

* Pipe Segment #6: [redacted] B2

* Total Length : 10 km (0 km to 10 km)

* Product Type(s): Methane(100%)

****

ction #1: 0km to 10km

Attribute	Value
Pipeline Diameter	914 mm
Pipe Wall Thickness	9.14 mm
Pipe Body Yield Strength	448 MPa
Pipe Body Seam Weld Type	High Quality Weld
Pipe Joint Type	Average Quality Weld
Line Age	25 years
Elevation Profile	N/A
Pressure Profile	6895 kPa
Operating Pressure Range	500 kPa
Cumulative Number of Pressure Cycles	2500 cycles
Operating Temperature	34.08 °C
Product Flow Rate	275.077 kg/s
Line Volume	100 %
Billing Abatement Threshold	90 %
Product Transportation Distance	3000 km
Block Valve Spacing	31.454 km
Time to Block Valve Closure	15 min
Detectable Release Volume	2000 m³
Time to Leak Detection	84 hr
Time to Leak Stoppage	24 hr
Depth of Cover	1 m
Adjacent Land Use	Remote - forested
ROW Accessibility	Far (difficult access)
ROW Condition	Average
ROW Patrol Frequency	Weekly
tification & Response System	System (limited awareness)
ossings/Special Terrain	Typical X-Country Conditions
Near Field Terrain	N/A
General Soil Corrosivity	Above Average (1000 - 2000 ohm*cm)
SCC Potential of Soil Environment	Likely Potential

External Pipe Coating Type	Coal Tar
External Pipe Coating Condition	Average
Cathodic Protection Level	Below Average
Presence of Coating Shielding	No
Electrical Interference/Casing Short	No
Product Corrosivity	Negligible (< 0.02 mm/yr)
ound Movement Potential	Low (1 in 10,000/km)
pe Damage Potential	Low (<= 1 in 100)
Surface Water within 300 m	N/A
Drinking Water within 5 km	N/A
Other Water within 5 km	N/A
Land Use within 5 km	N/A
Sensitive Environment within 10 km	N/A
Sensitive Groundwater within 10 km	N/A

Elevation Profile

kilometre post	line elevation (m)
N/A	N/A

Pressure Profile

kilometre post	operating pressure (kPa)
0	6895
10	6895

---------- Probability and Consequence Estimates ----------

Segment: [redacted] B2

Section #1: 0 km to 10 km

Failure Cause	Failure Probability (incidents/year) Small Leak	Large Leak	Rupture
External Corrosion	0.0066141	0.0007781	0.0003891
Internal Corrosion	0.0000071	0.0000008	0.0000004
Mechanical Damage	0.0000038	0.0000076	0.0000038
Ground Movement	0.0000020	0.0000040	0.0000040
ress Corrosion Cracking	0.0023344	0.0011672	0.0003891
am Weld Fatigue	0.0000000	0.0000000	0.0000000
Other	0.0016000	0.0002000	0.0002000
Cost of Failure ($ per incident)	$21143	$279013	$315080

****

* Pipe Segment #7: [redacted] B3

* Total Length : 10 km (0 km to 10 km)

* Product Type(s): Methane(100%)

****

Section #1: 0km to 10km

Attribute	Value
Pipeline Diameter	914 mm
Pipe Wall Thickness	9.14 mm
Pipe Body Yield Strength	448 MPa
Pipe Body Seam Weld Type	High Quality Weld
Pipe Joint Type	Average Quality Weld
Line Age	26 years
Elevation Profile	N/A
Pressure Profile	6895 kPa
Operating Pressure Range	500 kPa
Cumulative Number of Pressure Cycles	2600 cycles
Operating Temperature	44.25 °C
Product Flow Rate	275.077 kg/s
Line Volume	100 %
Billing Abatement Threshold	90 %
oduct Transportation Distance	3000 km
ock Valve Spacing	31.775 km
Time to Block Valve Closure	15 min
Detectable Release Volume	2000 m³
Time to Leak Detection	84 hr

Time to Leak Stoppage	24 hr
Depth of Cover	1 m
Adjacent Land Use	Remote - forested
ROW Accessibility	Far (difficult access)
ROW Condition	Average
ROW Patrol Frequency	Weekly
tification & Response System	System (limited awareness)
ossings/Special Terrain	Typical X-Country Conditions
Near Field Terrain	N/A
General Soil Corrosivity	Average (2000 - 5000 ohm*cm)
SCC Potential of Soil Environment	Unlikely Potential
External Pipe Coating Type	Asphalt
External Pipe Coating Condition	Average
Cathodic Protection Level	Below Average
Presence of Coating Shielding	No
Electrical Interference/Casing Short	No
Product Corrosivity	Negligible (< 0.02 mm/yr)
Ground Movement Potential	Low (1 in 10,000/km)
Pipe Damage Potential	Moderate (1 in 10)
Surface Water within 300 m	N/A
Drinking Water within 5 km	N/A
Other Water within 5 km	N/A
Land Use within 5 km	N/A
Sensitive Environment within 10 km	N/A
Sensitive Groundwater within 10 km	N/A

Elevation Profile

kilometre post	line elevation (m)
N/A	N/A

Pressure Profile

kilometre post	operating pressure (kPa)
0	6895
10	6895

---------- Probability and Consequence Estimates ----------*

gment: [redacted] B3

Section #1: 0 km to 10 km

Failure Cause	Failure Probability (incidents/year) Small Leak	Large Leak	Rupture
External Corrosion	0.0089961	0.0010584	0.0005292
Internal Corrosion	0.0000074	0.0000009	0.0000004
Mechanical Damage	0.0000038	0.0000076	0.0000038
Ground Movement	0.0000200	0.0000400	0.0000400
Stress Corrosion Cracking	0.0006350	0.0003175	0.0001058
Seam Weld Fatigue	0.0000000	0.0000000	0.0000000
Other	0.0016000	0.0002000	0.0002000
Cost of Failure ($ per incident)	$20850	$277198	$313104

****

* Pipe Segment #8: [redacted] B4

* Total Length : 10 km (0 km to 10 km)

* Product Type(s): Methane(100%)

****

Section #1: 0km to 10km

Attribute	Value
Pipeline Diameter	1067 mm
Pipe Wall Thickness	10.6 mm
Pipe Body Yield Strength	483 MPa
pe Body Seam Weld Type	High Quality Weld
.pe Joint Type	Average Quality Weld
Line Age	21 years
Elevation Profile	N/A
Pressure Profile	6895 kPa

Operating Pressure Range	500 kPa
Cumulative Number of Pressure Cycles	2100 cycles
Operating Temperature	23.95 °C
Product Flow Rate	412.616 kg/s
Line Volume	100 %
Billing Abatement Threshold	90 %
oduct Transportation Distance	3000 km
ock Valve Spacing	31.145 km
Time to Block Valve Closure	15 min
Detectable Release Volume	2000 m³
Time to Leak Detection	84 hr
Time to Leak Stoppage	24 hr
Depth of Cover	1 m
Adjacent Land Use	Parkland - forested
ROW Accessibility	Near (easy access)
ROW Condition	Average
ROW Patrol Frequency	Weekly
Notification & Response System	System (limited awareness)
Crossings/Special Terrain	Typical X-Country Conditions
Near Field Terrain	N/A
General Soil Corrosivity	Average (2000 - 5000 ohm*cm)
SCC Potential of Soil Environment	Unlikely Potential
External Pipe Coating Type	Tape
External Pipe Coating Condition	Average
Cathodic Protection Level	Below Average
Presence of Coating Shielding	No
Electrical Interference/Casing Short	No
Product Corrosivity	Negligible (< 0.02 mm/yr)
Ground Movement Potential	Negligible (<= 1 in 100,000/km)
Pipe Damage Potential	Moderate (1 in 10)
Surface Water within 300 m	N/A
Drinking Water within 5 km	N/A
Other Water within 5 km	N/A
Land Use within 5 km	N/A
Sensitive Environment within 10 km	N/A
nsitive Groundwater within 10 km	N/A

Elevation Profile

kilometre post	line elevation (m)
N/A	N/A

Pressure Profile

kilometre post	operating pressure (kPa)
0	6895
10	6895

---------- Probability and Consequence Estimates ----------

Segment: [redacted] 84

Section #1: 0 km to 10 km

Failure Cause	Failure Probability (incidents/year) Small Leak	Large Leak	Rupture
External Corrosion	0.0050771	0.0005973	0.0002987
Internal Corrosion	0.0000052	0.0000006	0.0000003
Mechanical Damage	0.0000010	0.0000021	0.0000010
Ground Movement	0.0000020	0.0000040	0.0000040
Stress Corrosion Cracking	0.0003584	0.0001792	0.0000597
Seam Weld Fatigue	0.0000000	0.0000000	0.0000000
Other	0.0016000	0.0002000	0.0002000
Cost of Failure ($ per incident)	$21455	$307273	$362562

****

Pipe Segment #9: [redacted] C1

Total Length : 10 km (0 km to 10 km)

* Product Type(s): Methane(100%)

****

Section #1: 0km to 10km

Attribute	Value
Pipeline Diameter	914 mm
Pipe Wall Thickness	12.7 mm
Pipe Body Yield Strength	455 MPa
'pe Body Seam Weld Type	High Quality Weld
pe Joint Type	Average Quality Weld
Line Age	22 years
Elevation Profile	N/A
Pressure Profile	6500 kPa
Operating Pressure Range	1.75973e-06 kPa
Cumulative Number of Pressure Cycles	0 cycles
Operating Temperature	10 °C
Product Flow Rate	205 kg/s
Line Volume	99 %
Billing Abatement Threshold	100 %
Product Transportation Distance	1000 km
Block Valve Spacing	16 km
Time to Block Valve Closure	5 min
Detectable Release Volume	2000 m^3
Time to Leak Detection	168 hr
Time to Leak Stoppage	5 hr
Depth of Cover	1.2 m
Adjacent Land Use	Agricultural
ROW Accessibility	Far (difficult access)
ROW Condition	Average
ROW Patrol Frequency	Bi-Weekly
Notification & Response System	System (average awareness)
Crossings/Special Terrain	Typical X-Country Conditions
Near Field Terrain	N/A
General Soil Corrosivity	Below Average (5000 - 10,000 ohm*cm)
SCC Potential of Soil Environment	No Potential
External Pipe Coating Type	Coal Tar
External Pipe Coating Condition	Above Average
'thodic Protection Level	Above Average
.esence of Coating Shielding	No
Electrical Interference/Casing Short	No
Product Corrosivity	Negligible (< 0.02 mm/yr)
Ground Movement Potential	Low (1 in 10,000/km)
Pipe Damage Potential	Moderate (1 in 10)
Surface Water within 300 m	N/A
Drinking Water within 5 km	N/A
Other Water within 5 km	N/A
Land Use within 5 km	N/A
Sensitive Environment within 10 km	N/A
Sensitive Groundwater within 10 km	N/A

Elevation Profile

kilometre post	line elevation (m)
N/A	N/A

Pressure Profile

kilometre post	operating pressure (kPa)
0	7000
10	6000

---------- Probability and Consequence Estimates ----------

Segment: [redacted] C1

Section #1: 0 km to 10 km

Failure Cause	Failure Probability (incidents/year) Small Leak	Large Leak	Rupture
'ternal Corrosion	0.0000245	0.0000029	0.0000014
.ternal Corrosion	0.0000045	0.0000005	0.0000003
Mechanical Damage	0.0000002	0.0000004	0.0000002
Ground Movement	0.0000200	0.0000400	0.0000400
Stress Corrosion Cracking	0.0000000	0.0000000	0.0000000

Seam Weld Fatigue	0.0000000	0.0000000	0.0000000
Other	0.0016000	0.0002000	0.0002000
Cost of Failure ($ per incident)	$18158	$583162	$844952

****

Pipe Segment #10: [redacted] C2

Total Length : 10 km (0 km to 10 km)

* Product Type(s): Methane(100%)

****

Section #1: 0km to 10km

Attribute	Value
Pipeline Diameter	914 mm
Pipe Wall Thickness	12.7 mm
Pipe Body Yield Strength	455 MPa
Pipe Body Seam Weld Type	High Quality Weld
Pipe Joint Type	Average Quality Weld
Line Age	22 years
Elevation Profile	N/A
Pressure Profile	6500 kPa
Operating Pressure Range	1.75973e-06 kPa
Cumulative Number of Pressure Cycles	0 cycles
Operating Temperature	10 °C
Product Flow Rate	205 kg/s
Line Volume	99 %
Billing Abatement Threshold	100 %
Product Transportation Distance	1000 km
Block Valve Spacing	16 km
Time to Block Valve Closure	5 min
Detectable Release Volume	2000 m³
Time to Leak Detection	168 hr
Time to Leak Stoppage	5 hr
Depth of Cover	1.2 m
Adjacent Land Use	Residential - Urban
ROW Accessibility	Near (easy access)
ROW Condition	Average
ROW Patrol Frequency	Bi-Weekly
Notification & Response System	System (average awareness)
Crossings/Special Terrain	Typical X-Country Conditions
Near Field Terrain	N/A
General Soil Corrosivity	Below Average (5000 - 10,000 ohm*cm)
SCC Potential of Soil Environment	No Potential
External Pipe Coating Type	Coal Tar
External Pipe Coating Condition	Above Average
Cathodic Protection Level	Above Average
Presence of Coating Shielding	No
Electrical Interference/Casing Short	No
Product Corrosivity	Negligible (< 0.02 mm/yr)
Ground Movement Potential	Low (1 in 10,000/km)
Pipe Damage Potential	Moderate (1 in 10)
Surface Water within 300 m	N/A
Drinking Water within 5 km	N/A
Other Water within 5 km	N/A
Land Use within 5 km	N/A
Sensitive Environment within 10 km	N/A
Sensitive Groundwater within 10 km	N/A

Elevation Profile

kilometre post	line elevation (m)
N/A	N/A

Pressure Profile

kilometre post	operating pressure (kPa)
	6500
10	6500

---------- Probability and Consequence Estimates ----------

Segment: [redacted] C2
Section #1: 0 km to 10 km

Failure Cause	Failure Probability (incidents/year) Small Leak	Large Leak	Rupture
‹ternal Corrosion	0.0000245	0.0000029	0.0000014
.ternal Corrosion	0.0000045	0.0000005	0.0000003
Mechanical Damage	0.0000019	0.0000038	0.0000019
Ground Movement	0.0000200	0.0000400	0.0000400
Stress Corrosion Cracking	0.0000000	0.0000000	0.0000000
Seam Weld Fatigue	0.0000000	0.0000000	0.0000000
Other	0.0016000	0.0002000	0.0002000
Cost of Failure ($ per incident)	$115910	$4071780	$719497000

****
* Pipe Segment #11: [redacted] C3
* Total Length : 10 km (0 km to 10 km)
* Product Type(s): Methane(100%)
****

Section #1: 0km to 10km

Attribute	Value
Pipeline Diameter	300 mm
Pipe Wall Thickness	7.14 mm
Pipe Body Yield Strength	349 MPa
Pipe Body Seam Weld Type	Seamless
Pipe Joint Type	Average Quality Weld
Line Age	26 years
Elevation Profile	N/A
Pressure Profile	5100 kPa
Operating Pressure Range	500 kPa
Cumulative Number of Pressure Cycles	9000 cycles
?erating Temperature	10 °C
oduct Flow Rate	15.55 kg/s
Line Volume	80 %
Billing Abatement Threshold	100 %
Product Transportation Distance	1000 km
Block Valve Spacing	4 km
Time to Block Valve Closure	5 min
Detectable Release Volume	2000 m³
Time to Leak Detection	168 hr
Time to Leak Stoppage	5 hr
Depth of Cover	1.2 m
Adjacent Land Use	Industrial
ROW Accessibility	Near (easy access)
ROW Condition	Average
ROW Patrol Frequency	Bi-Weekly
Notification & Response System	System (average awareness)
Crossings/Special Terrain	Typical X-Country Conditions
Near Field Terrain	N/A
General Soil Corrosivity	Average (2000 - 5000 ohm*cm)
SCC Potential of Soil Environment	No Potential
External Pipe Coating Type	Coal Tar
External Pipe Coating Condition	Average
Cathodic Protection Level	Average
Presence of Coating Shielding	No
Electrical Interference/Casing Short	Yes
Product Corrosivity	Negligible (< 0.02 mm/yr)
Ground Movement Potential	Low (1 in 10,000/km)
Pipe Damage Potential	Moderate (1 in 10)
Surface Water within 300 m	N/A
?inking Water within 5 km	N/A
.her Water within 5 km	N/A
Land Use within 5 km	N/A
Sensitive Environment within 10 km	N/A
Sensitive Groundwater within 10 km	N/A

Elevation Profile

kilometre post	line elevation (m)
N/A	N/A

Pressure Profile

ometre post	operating pressure (kPa)
	5200
10	5000

---------- Probability and Consequence Estimates ----------

Segment: [redacted] C3

Section #1: 0 km to 10 km

Failure Cause	Failure Probability (incidents/year) Small Leak	Large Leak	Rupture
External Corrosion	0.0015385	0.0001810	0.0000905
Internal Corrosion	0.0000095	0.0000011	0.0000006
Mechanical Damage	0.0004975	0.0009950	0.0004975
Ground Movement	0.0000200	0.0000400	0.0000400
Stress Corrosion Cracking	0.0000000	0.0000000	0.0000000
Seam Weld Fatigue	0.0000000	0.0000000	0.0000000
Other	0.0016000	0.0002000	0.0002000
Cost of Failure ($ per incident)	$23917	$522204	$5756080

****

* Pipe Segment #12: [redacted] D1

* Total Length : 10 km (0 km to 10 km)

* Product Type(s): Methane(100%)

****

Section #1: 0km to 10km

ribute	Value
peline Diameter	914 mm
Pipe Wall Thickness	11.05 mm
Pipe Body Yield Strength	483 MPa
Pipe Body Seam Weld Type	High Quality Weld
Pipe Joint Type	High Quality Weld
Line Age	20 years
Elevation Profile	N/A
Pressure Profile	5826 kPa
Operating Pressure Range	441.3 kPa
Cumulative Number of Pressure Cycles	20 cycles
Operating Temperature	22 °C
Product Flow Rate	186 kg/s
Line Volume	73 %
Billing Abatement Threshold	85 %
Product Transportation Distance	1000 km
Block Valve Spacing	32 km
Time to Block Valve Closure	53.3 min
Detectable Release Volume	2000 m³
Time to Leak Detection	48 hr
Time to Leak Stoppage	18 hr
Depth of Cover	1.8 m
Adjacent Land Use	Residential - Urban
ROW Accessibility	Near (easy access)
ROW Condition	Above Average
ROW Patrol Frequency	Monthly
Notification & Response System	System (high awareness)
Crossings/Special Terrain	Typical X-Country Conditions
Near Field Terrain	N/A
eral Soil Corrosivity	Average (2000 - 5000 ohm*cm)
Potential of Soil Environment	Unlikely Potential
External Pipe Coating Type	Tape
External Pipe Coating Condition	Above Average
Cathodic Protection Level	Average

Presence of Coating Shielding	No
Electrical Interference/Casing Short	No
Product Corrosivity	Low (0.02 - 0.1 mm/yr)
Ground Movement Potential	Low (1 in 10,000/km)
Pipe Damage Potential	Moderate (1 in 10)
Surface Water within 300 m	N/A
inking Water within 5 km	N/A
ıer Water within 5 km	N/A
Land Use within 5 km	N/A
Sensitive Environment within 10 km	N/A
Sensitive Groundwater within 10 km	N/A

Elevation Profile

kilometre post	line elevation (m)
N/A	N/A

Pressure Profile

kilometre post	operating pressure (kPa)
0	5826
10	5826

---------- Probability and Consequence Estimates ----------

Segment: [redacted] D1

Section #1: 0 km to 10 km

Failure Cause	Failure Probability (incidents/year) Small Leak	Large Leak	Rupture
External Corrosion	0.0006932	0.0000816	0.0000408
Internal Corrosion	0.0000235	0.0000028	0.0000014
Mechanical Damage	0.0000051	0.0000101	0.0000051
Ground Movement	0.0000100	0.0000200	0.0000200
Stress Corrosion Cracking	0.0000000	0.0000000	0.0000000
Seam Weld Fatigue	0.0000000	0.0000000	0.0000000
Other	0.0016000	0.0002000	0.0002000
st of Failure ($ per incident)	$104878	$3333020	$635744000

****

* Pipe Segment #13: [redacted] D2

* Total Length : 10 km (0 km to 10 km)

* Product Type(s): Methane(100%)

****

Section #1: 0km to 10km

Attribute	Value
Pipeline Diameter	914 mm
Pipe Wall Thickness	9.79 mm
Pipe Body Yield Strength	483 MPa
Pipe Body Seam Weld Type	High Quality Weld
Pipe Joint Type	High Quality Weld
Line Age	17 years
Elevation Profile	N/A
Pressure Profile	8274 kPa
Operating Pressure Range	434.4 kPa
Cumulative Number of Pressure Cycles	17 cycles
Operating Temperature	11 °C
Product Flow Rate	264 kg/s
Line Volume	73 %
Billing Abatement Threshold	85 %
Product Transportation Distance	1000 km
Block Valve Spacing	32 km
Time to Block Valve Closure	66.7 min
tectable Release Volume	2000 m³
me to Leak Detection	720 hr
Time to Leak Stoppage	240 hr
Depth of Cover	0.8 m
Adjacent Land Use	Remote - forested

ROW Accessibility	Far (difficult access)
ROW Condition	Below Average
ROW Patrol Frequency	Monthly
Notification & Response System	System (high awareness)
Crossings/Special Terrain	Typical X-Country Conditions
Near Field Terrain	N/A
[illegible]neral Soil Corrosivity	Above Average (1000 - 2000 ohm*cm)
[illegible] Potential of Soil Environment	Definite Potential
External Pipe Coating Type	Tape
External Pipe Coating Condition	Average
Cathodic Protection Level	Average
Presence of Coating Shielding	No
Electrical Interference/Casing Short	No
Product Corrosivity	Low (0.02 - 0.1 mm/yr)
Ground Movement Potential	Low (1 in 10,000/km)
Pipe Damage Potential	Moderate (1 in 10)
Surface Water within 300 m	N/A
Drinking Water within 5 km	N/A
Other Water within 5 km	N/A
Land Use within 5 km	N/A
Sensitive Environment within 10 km	N/A
Sensitive Groundwater within 10 km	N/A

Elevation Profile

kilometre post	line elevation (m)
N/A	N/A

Pressure Profile

kilometre post	operating pressure (kPa)
0	8274
10	8274

---------- Probability and Consequence Estimates ----------

Segment: [redacted] D2

Section #1: 0 km to 10 km

Failure Cause	Failure Probability (incidents/year) Small Leak	Large Leak	Rupture
External Corrosion	0.0014632	0.0001721	0.0000861
Internal Corrosion	0.0000226	0.0000027	0.0000013
Mechanical Damage	0.0000021	0.0000043	0.0000021
Ground Movement	0.0000100	0.0000200	0.0000200
Stress Corrosion Cracking	0.0010328	0.0005164	0.0001721
Seam Weld Fatigue	0.0000000	0.0000000	0.0000000
Other	0.0016000	0.0002000	0.0002000
Cost of Failure ($ per incident)	$69083	$307998	$409320

****

* Pipe Segment #14: [redacted] D3

* Total Length : 10 km (0 km to 10 km)

* Product Type(s): Methane(100%)

****

Section #1: 0km to 10km

Attribute	Value
Pipeline Diameter	323.9 mm
Pipe Wall Thickness	4.78 mm
Pipe Body Yield Strength	290 MPa
Pipe Body Seam Weld Type	High Quality Weld
Pipe Joint Type	Average Quality Weld
Line Age	29 years
[illegible]evation Profile	N/A
[illegible]ssure Profile	6150 kPa
Operating Pressure Range	482.6 kPa
Cumulative Number of Pressure Cycles	29 cycles
Operating Temperature	29 °C

Product Flow Rate	24.7 kg/s
Line Volume	104 %
Billing Abatement Threshold	85 %
Product Transportation Distance	1000 km
Block Valve Spacing	32 km
Time to Block Valve Closure	133.3 min
etectable Release Volume	2000 m³
me to Leak Detection	720 hr
Time to Leak Stoppage	240 hr
Depth of Cover	0.8 m
Adjacent Land Use	Parkland - forested
ROW Accessibility	Far (difficult access)
ROW Condition	Average
ROW Patrol Frequency	Monthly
Notification & Response System	System (average awareness)
Crossings/Special Terrain	Typical X-Country Conditions
Near Field Terrain	N/A
General Soil Corrosivity	Below Average (5000 - 10,000 ohm*cm)
SCC Potential of Soil Environment	Likely Potential
External Pipe Coating Type	Tape
External Pipe Coating Condition	Average
Cathodic Protection Level	Average
Presence of Coating Shielding	No
Electrical Interference/Casing Short	No
Product Corrosivity	Low (0.02 - 0.1 mm/yr)
Ground Movement Potential	Low (1 in 10,000/km)
Pipe Damage Potential	Moderate (1 in 10)
Surface Water within 300 m	N/A
Drinking Water within 5 km	N/A
Other Water within 5 km	N/A
Land Use within 5 km	N/A
Sensitive Environment within 10 km	N/A
Sensitive Groundwater within 10 km	N/A

Elevation Profile

ilometre post	line elevation (m)
/A	N/A

Pressure Profile

kilometre post	operating pressure (kPa)
0	6150
10	6150

---------- Probability and Consequence Estimates ----------

Segment: [redacted] D3

Section #1: 0 km to 10 km

Failure Cause	Failure Probability (incidents/year) Small Leak	Large Leak	Rupture
External Corrosion	0.0045050	0.0005300	0.0002650
Internal Corrosion	0.0000789	0.0000093	0.0000046
Mechanical Damage	0.0001201	0.0002401	0.0001201
Ground Movement	0.0000200	0.0000400	0.0000400
Stress Corrosion Cracking	0.0015900	0.0007950	0.0002650
Seam Weld Fatigue	0.0000000	0.0000000	0.0000000
Other	0.0016000	0.0002000	0.0002000
Cost of Failure ($ per incident)	$24872	$222836	$227462

****

* Pipe Segment #15: [redacted] D4

* Total Length : 10 km (0 km to 10 km)

* Product Type(s): Methane(100%)

****

Section #1: 0km to 10km

Attribute	Value

Pipeline Diameter	457 mm
Pipe Wall Thickness	6.35 mm
Pipe Body Yield Strength	414 MPa
Pipe Body Seam Weld Type	High Quality Weld
Pipe Joint Type	Average Quality Weld
Line Age	30 years
Elevation Profile	N/A
Pressure Profile	9191 kPa
Operating Pressure Range	1006.6 kPa
Cumulative Number of Pressure Cycles	30 cycles
Operating Temperature	41 °C
Product Flow Rate	73.4 kg/s
Line Volume	81 %
Billing Abatement Threshold	85 %
Product Transportation Distance	1000 km
Block Valve Spacing	32 km
Time to Block Valve Closure	66.7 min
Detectable Release Volume	2000 m³
Time to Leak Detection	720 hr
Time to Leak Stoppage	240 hr
Depth of Cover	0.8 m
Adjacent Land Use	Parkland - forested
ROW Accessibility	Far (difficult access)
ROW Condition	Below Average
ROW Patrol Frequency	Monthly
Notification & Response System	System (high awareness)
Crossings/Special Terrain	Typical X-Country Conditions
Near Field Terrain	N/A
General Soil Corrosivity	High (< 1000 ohm*cm)
SCC Potential of Soil Environment	Definite Potential
External Pipe Coating Type	Tape
External Pipe Coating Condition	Below Average
Cathodic Protection Level	Average
Presence of Coating Shielding	Yes
Electrical Interference/Casing Short	No
Product Corrosivity	Low (0.02 - 0.1 mm/yr)
Ground Movement Potential	Low (1 in 10,000/km)
Pipe Damage Potential	Moderate (1 in 10)
Surface Water within 300 m	N/A
Drinking Water within 5 km	N/A
Other Water within 5 km	N/A
Land Use within 5 km	N/A
Sensitive Environment within 10 km	N/A
Sensitive Groundwater within 10 km	N/A

Elevation Profile

kilometre post	line elevation (m)
N/A	N/A

Pressure Profile

kilometre post	operating pressure (kPa)
0	9191
10	9191

---------- Probability and Consequence Estimates ----------

Segment: [redacted] D4

Section #1: 0 km to 10 km

Failure Cause	Failure Probability (incidents/year) Small Leak	Large Leak	Rupture
External Corrosion	0.2907560	0.0342066	0.0171033
Internal Corrosion	0.0000614	0.0000072	0.0000036
Mechanical Damage	0.0000666	0.0001333	0.0000666
Ground Movement	0.0000200	0.0000400	0.0000400
Stress Corrosion Cracking	0.2052400	0.1026200	0.0342066
Seam Weld Fatigue	0.0000000	0.0000000	0.0000000
Other	0.0016000	0.0002000	0.0002000

Cost of Failure ($ per Incident) $42014 $253443 $295702

****
* Pipe Segment #16: [redacted] D5
* Total Length : 10 km (0 km to 10 km)
* Product Type(s): Methane(100%)
****

Section #1: 0km to 10km

Attribute	Value
Pipeline Diameter	406.4 mm
Pipe Wall Thickness	5.99 mm
Pipe Body Yield Strength	359 MPa
Pipe Body Seam Weld Type	High Quality Weld
Pipe Joint Type	High Quality Weld
Line Age	21 years
Elevation Profile	N/A
Pressure Profile	8453 kPa
Operating Pressure Range	1296.2 kPa
Cumulative Number of Pressure Cycles	21 cycles
Operating Temperature	13 °C
Product Flow Rate	53.3 kg/s
Line Volume	72 %
Billing Abatement Threshold	85 %
Product Transportation Distance	1000 km
Block Valve Spacing	32 km
Time to Block Valve Closure	76.2 min
Detectable Release Volume	2000 m³
Time to Leak Detection	720 hr
Time to Leak Stoppage	18 hr
Depth of Cover	0.8 m
Adjacent Land Use	Agricultural
ROW Accessibility	Near (easy access)
ROW Condition	Average
ROW Patrol Frequency	Monthly
tification & Response System	System (high awareness)
Crossings/Special Terrain	Typical X-Country Conditions
Near Field Terrain	N/A
General Soil Corrosivity	Below Average (5000 - 10,000 ohm*cm)
SCC Potential of Soil Environment	Likely Potential
External Pipe Coating Type	Tape
External Pipe Coating Condition	Average
Cathodic Protection Level	Average
Presence of Coating Shielding	No
Electrical Interference/Casing Short	No
Product Corrosivity	Low (0.02 - 0.1 mm/yr)
Ground Movement Potential	Low (1 in 10,000/km)
Pipe Damage Potential	Moderate (1 in 10)
Surface Water within 300 m	N/A
Drinking Water within 5 km	N/A
Other Water within 5 km	N/A
Land Use within 5 km	N/A
Sensitive Environment within 10 km	N/A
Sensitive Groundwater within 10 km	N/A

Elevation Profile

kilometre post	line elevation (m)
N/A	N/A

Pressure Profile

kilometre post	operating pressure (kPa)
0	8453
10	8453

---------- Probability and Consequence Estimates ----------*
Segment: [redacted] D5
Section #1: 0 km to 10 km

Ground Movement Potential	Low (<= 1 in 20,000/km)
Pipe Damage Potential	Low (<= 1 in 100)
Surface Water within 300 m	N/A
Drinking Water within 5 km	N/A
Other Water within 5 km	N/A
Land Use within 5 km	N/A
Sensitive Environment within 10 km	N/A
Sensitive Groundwater within 10 km	N/A

Elevation Profile

kilometre post	line elevation (m)
N/A	N/A

Pressure Profile

kilometre post	operating pressure (kPa)
0	5695
10	5695

---------- Probability and Consequence Estimates ----------

Segment: [redacted] D7

Section #1: 0 km to 10 km

Failure Cause	Failure Probability (incidents/year) Small Leak	Large Leak	Rupture
External Corrosion	0.0008963	0.0001054	0.0000527
Internal Corrosion	0.0000446	0.0000053	0.0000026
Mechanical Damage	0.0000125	0.0000249	0.0000125
Ground Movement	0.0000020	0.0000040	0.0000040
Stress Corrosion Cracking	0.0000633	0.0000316	0.0000105
Seam Weld Fatigue	0.0000000	0.0000000	0.0000000
Other	0.0016000	0.0002000	0.0002000
Cost of Failure ($ per incident)	$18670	$275308	$1803900

****

Pipe Segment #19: [redacted] D8

* Total Length : 10 km (0 km to 10 km)

* Product Type(s): Methane(100%)

****

Section #1: 0km to 10km

Attribute	Value
Pipeline Diameter	914 mm
Pipe Wall Thickness	8.74 mm
Pipe Body Yield Strength	448 MPa
Pipe Body Seam Weld Type	High Quality Weld
Pipe Joint Type	Average Quality Weld
Line Age	29 years
Elevation Profile	N/A
Pressure Profile	8563 kPa
Operating Pressure Range	172.4 kPa
Cumulative Number of Pressure Cycles	29 cycles
Operating Temperature	31 °C
Product Flow Rate	274 kg/s
Line Volume	53 %
Billing Abatement Threshold	85 %
Product Transportation Distance	1000 km
Block Valve Spacing	32 km
Time to Block Valve Closure	53.3 min
Detectable Release Volume	2000 m³
Time to Leak Detection	720 hr
Time to Leak Stoppage	18 hr
Depth of Cover	0.8 m
Adjacent Land Use	Agricultural
ROW Accessibility	Near (easy access)
ROW Condition	Above Average
ROW Patrol Frequency	Monthly

Notification & Response System	System (High Awareness)
Crossings/Special Terrain	Typical X-Country Conditions
Near Field Terrain	N/A
General Soil Corrosivity	Above Average (1000 - 2000 ohm*cm)
SCC Potential of Soil Environment	Unlikely Potential
External Pipe Coating Type	Asphalt
ternal Pipe Coating Condition	Above Average
thodic Protection Level	Average
Presence of Coating Shielding	No
Electrical Interference/Casing Short	No
Product Corrosivity	Low (0.02 - 0.1 mm/yr)
Ground Movement Potential	Low (1 in 10,000/km)
Pipe Damage Potential	Low (<= 1 in 100)
Surface Water within 300 m	N/A
Drinking Water within 5 km	N/A
Other Water within 5 km	N/A
Land Use within 5 km	N/A
Sensitive Environment within 10 km	N/A
Sensitive Groundwater within 10 km	N/A

Elevation Profile

kilometre post	line elevation (m)
N/A	N/A

Pressure Profile

kilometre post	operating pressure (kPa)
0	8563
10	8563

---------- Probability and Consequence Estimates ----------

Segment: [redacted] 08

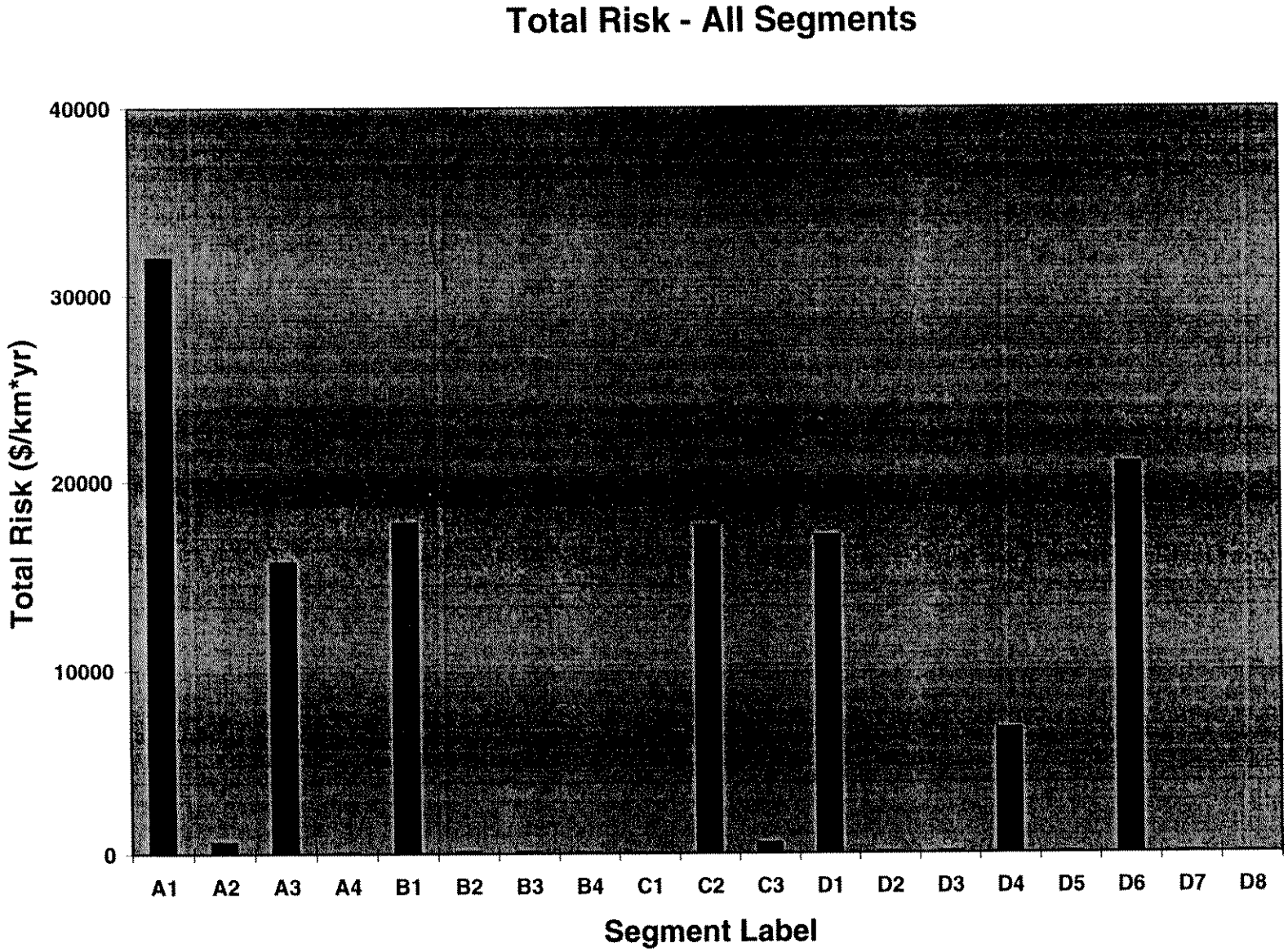
Section #1: 0 km to 10 km

Failure Cause	Failure Probability (incidents/year) Small Leak	Large Leak	Rupture
ternal Corrosion	0.0023261	0.0002737	0.0001368
Internal Corrosion	0.0000432	0.0000051	0.0000025
Mechanical Damage	0.0000487	0.0000973	0.0000487
Ground Movement	0.0000020	0.0000040	0.0000040
Stress Corrosion Cracking	0.0001642	0.0000821	0.0000274
Seam Weld Fatigue	0.0000000	0.0000000	0.0000000
Other	0.0016000	0.0002000	0.0002000
Cost of Failure ($ per incident)	$22706	$303806	$696949

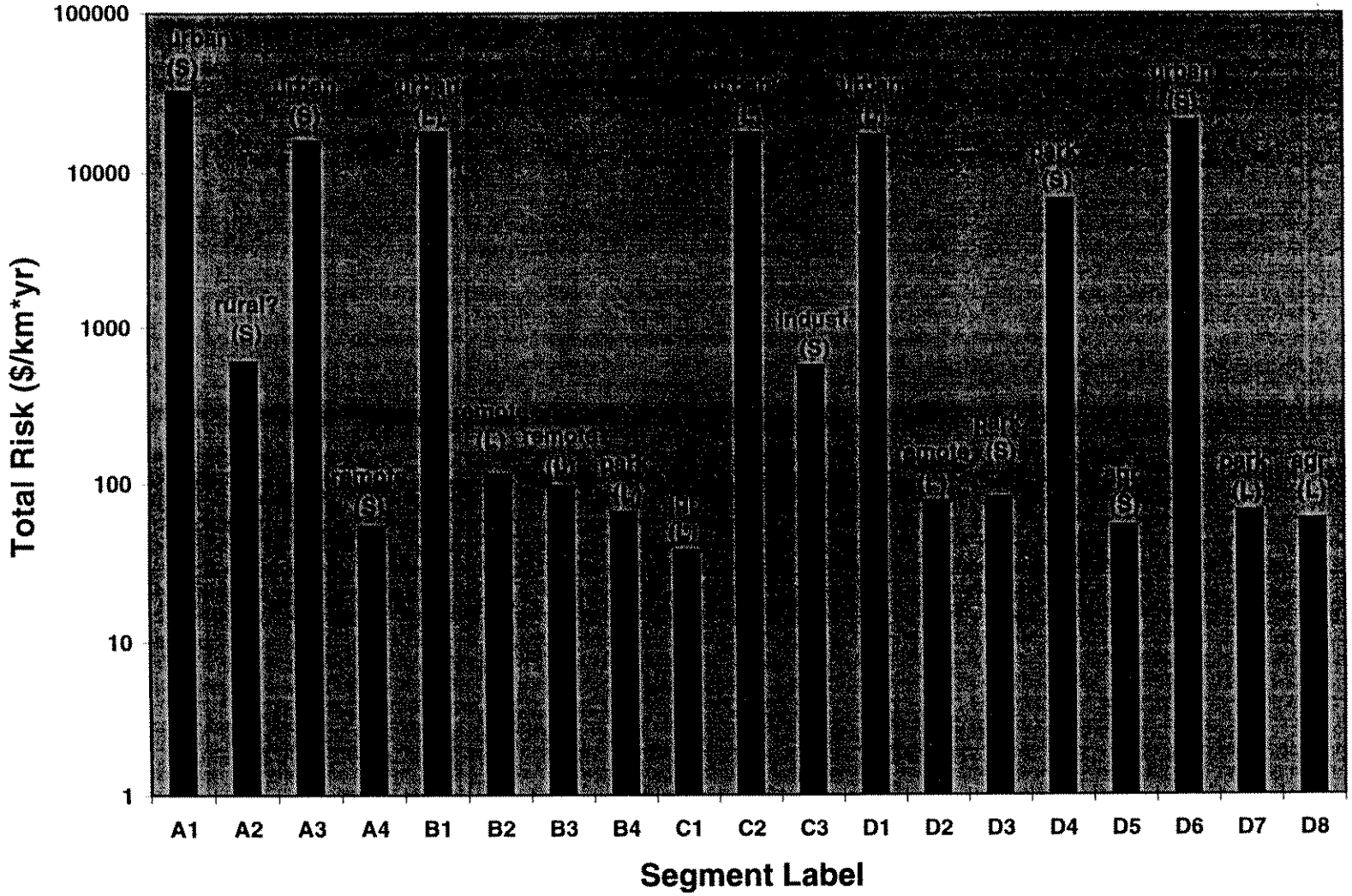
Section D

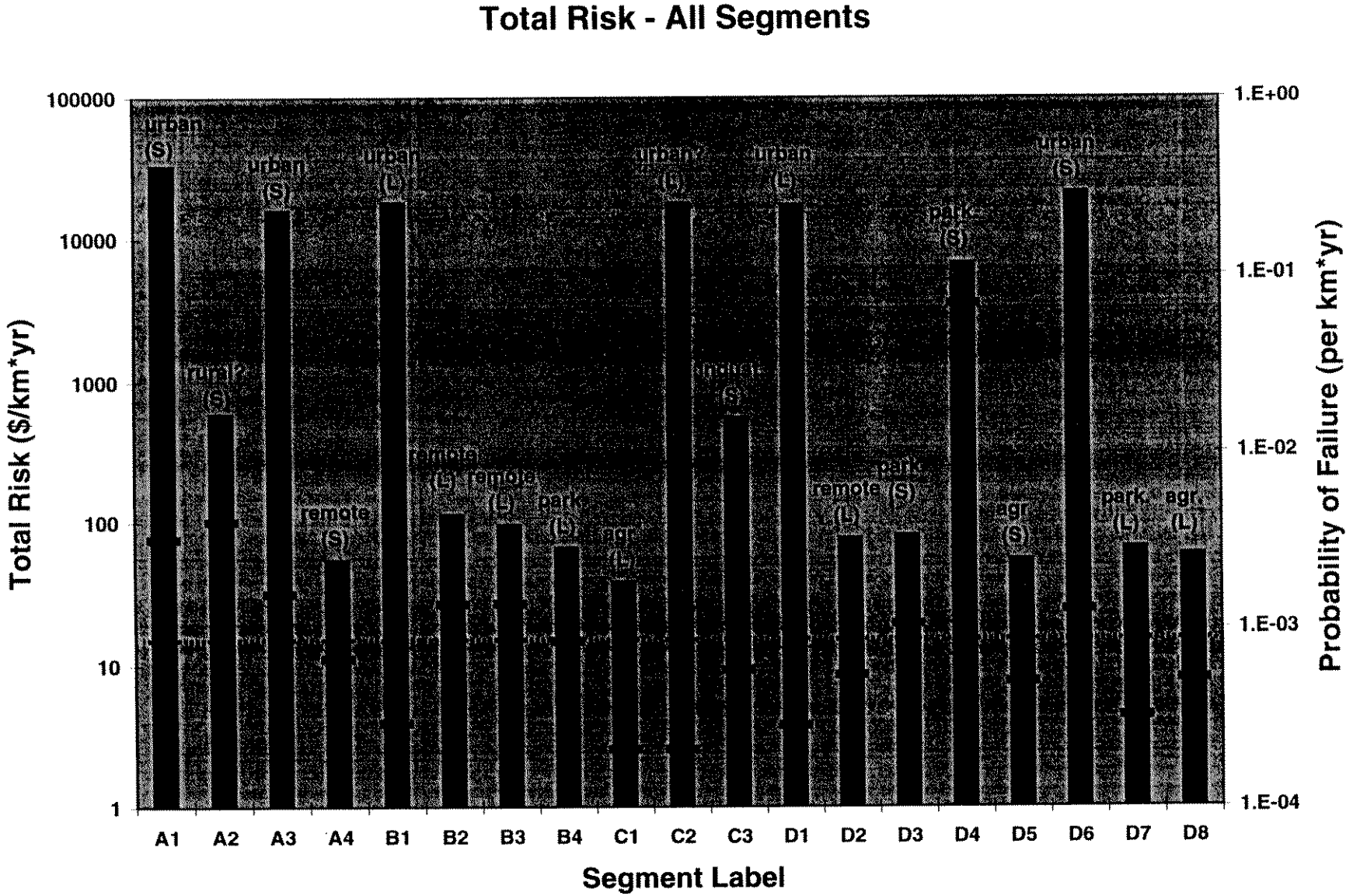
Model Output for On Shore Gas Pipelines

General Risk Ranking (all segments)


Total Risk - All Segments
Total Risk ($/km*yr)
40000
30000
20000
10000
0
A1
A2
A3
A4
B1
B2
B3
B4
C1
C2
C3
D1
D2
D3
D4
D5
D6
D7
D8
Segment Label

Total Risk - All Segments




Total Risk - All Segments
Total Risk ($/km*yr)
Probability of Failure (per km*yr)
Segment Label
100000
10000
1000
100
10
1
1.E+00
1.E-01
1.E-02
1.E-03
1.E-04
A1
A2
A3
A4
B1
B2
B3
B4
C1
C2
C3
D1
D2
D3
D4
D5
D6
D7
D8
urban (S)
rural (S)
urban (S)
remote (S)
urban (L)
rural (L)
remote (S)
park (L)
agr (L)
urban (S)
rural (S)
urban (L)
park (S)
remote (L)
park (S)
agr (S)
urban (S)
park (L)
agr (L)

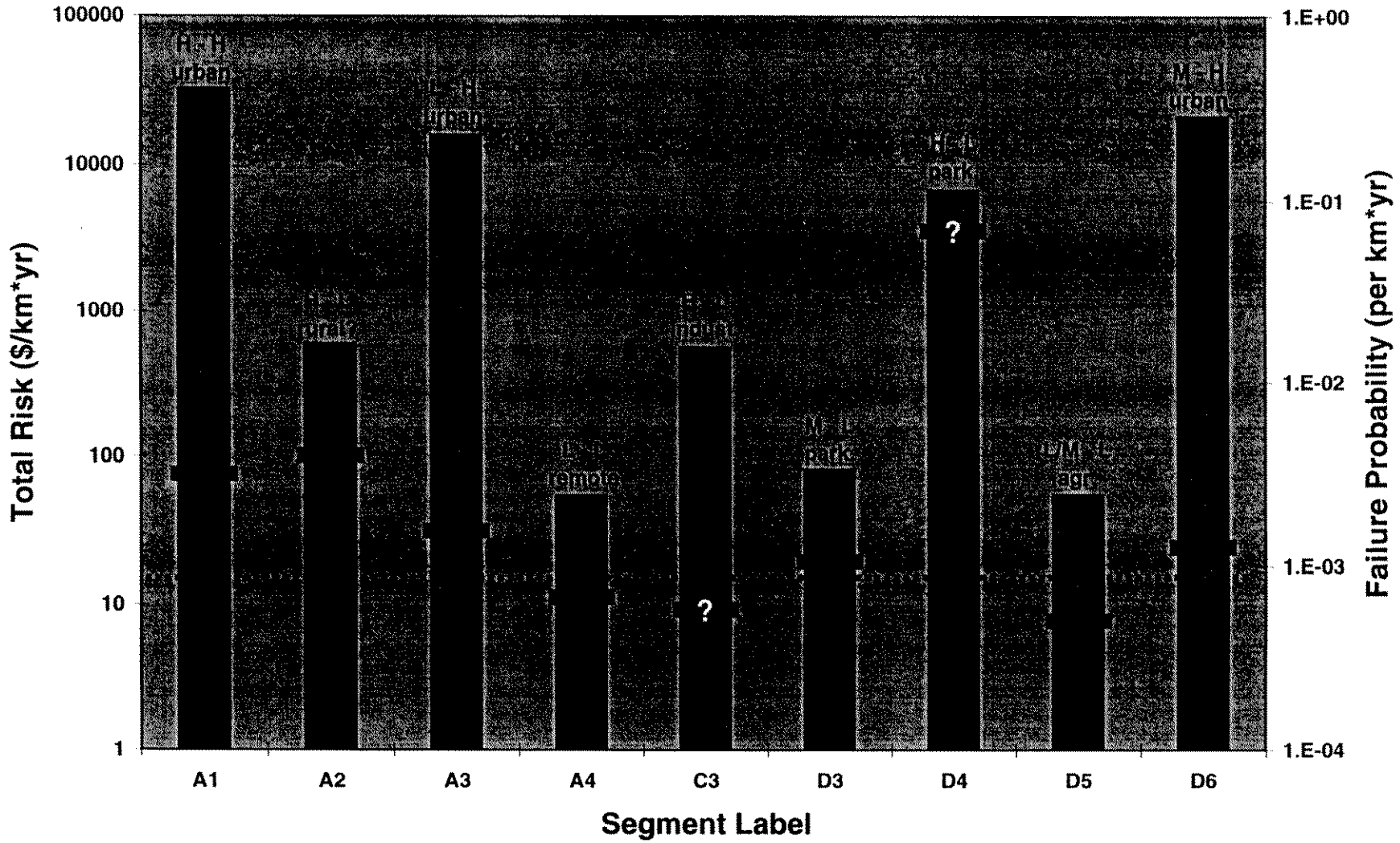
Rank	Segment Name	Failure Cause	Segment	Cause	Total Risk ($/km yr)	Prob. Fail (per km yr)	Exp. Cost ($/km yr)	Exp. Fatal. (per km yr)
1		All Causes Combined	A1	#N/A	3.20E+04	3.18E-03	1.07E+04	1.07E-02
2		All Causes Combined	D6	#N/A	2.09E+04	1.27E-03	6.98E+03	6.97E-03
3		All Causes Combined	B1	#N/A	1.78E+04	3.01E-04	5.83E+03	5.98E-03
4		All Causes Combined	C2	#N/A	1.76E+04	2.14E-04	5.79E+03	5.93E-03
5		All Causes Combined	D1	#N/A	1.71E+04	2.91E-04	5.61E+03	5.75E-03
6		All Causes Combined	A3	#N/A	1.58E+04	1.56E-03	5.31E+03	5.22E-03
7		All Causes Combined	D4	#N/A	6.71E+03	6.87E-02	6.71E+03	0.00E+00
8		All Causes Combined	A2	#N/A	5.96E+02	4.01E-03	3.91E+02	1.03E-04
9		All Causes Combined	C3	#N/A	5.60E+02	5.91E-04	4.06E+02	7.67E-05
10		All Causes Combined	B2	#N/A	1.14E+02	1.37E-03	1.14E+02	0.00E+00
11		All Causes Combined	B3	#N/A	9.60E+01	1.38E-03	9.60E+01	0.00E+00
12		All Causes Combined	D3	#N/A	8.05E+01	1.06E-03	8.05E+01	0.00E+00
13		All Causes Combined	D2	#N/A	7.64E+01	5.53E-04	7.64E+01	0.00E+00
14		All Causes Combined	D7	#N/A	6.60E+01	3.27E-04	6.60E+01	0.00E+00
15		All Causes Combined	B4	#N/A	6.58E+01	8.59E-04	6.58E+01	0.00E+00
16		All Causes Combined	D8	#N/A	5.88E+01	5.27E-04	5.03E+01	4.26E-06
17		All Causes Combined	A4	#N/A	5.39E+01	6.89E-04	5.39E+01	0.00E+00
18		All Causes Combined	D5	#N/A	5.38E+01	5.08E-04	5.12E+01	1.29E-06
19		All Causes Combined	C1	#N/A	3.77E+01	2.13E-04	3.40E+01	1.83E-06

Section E

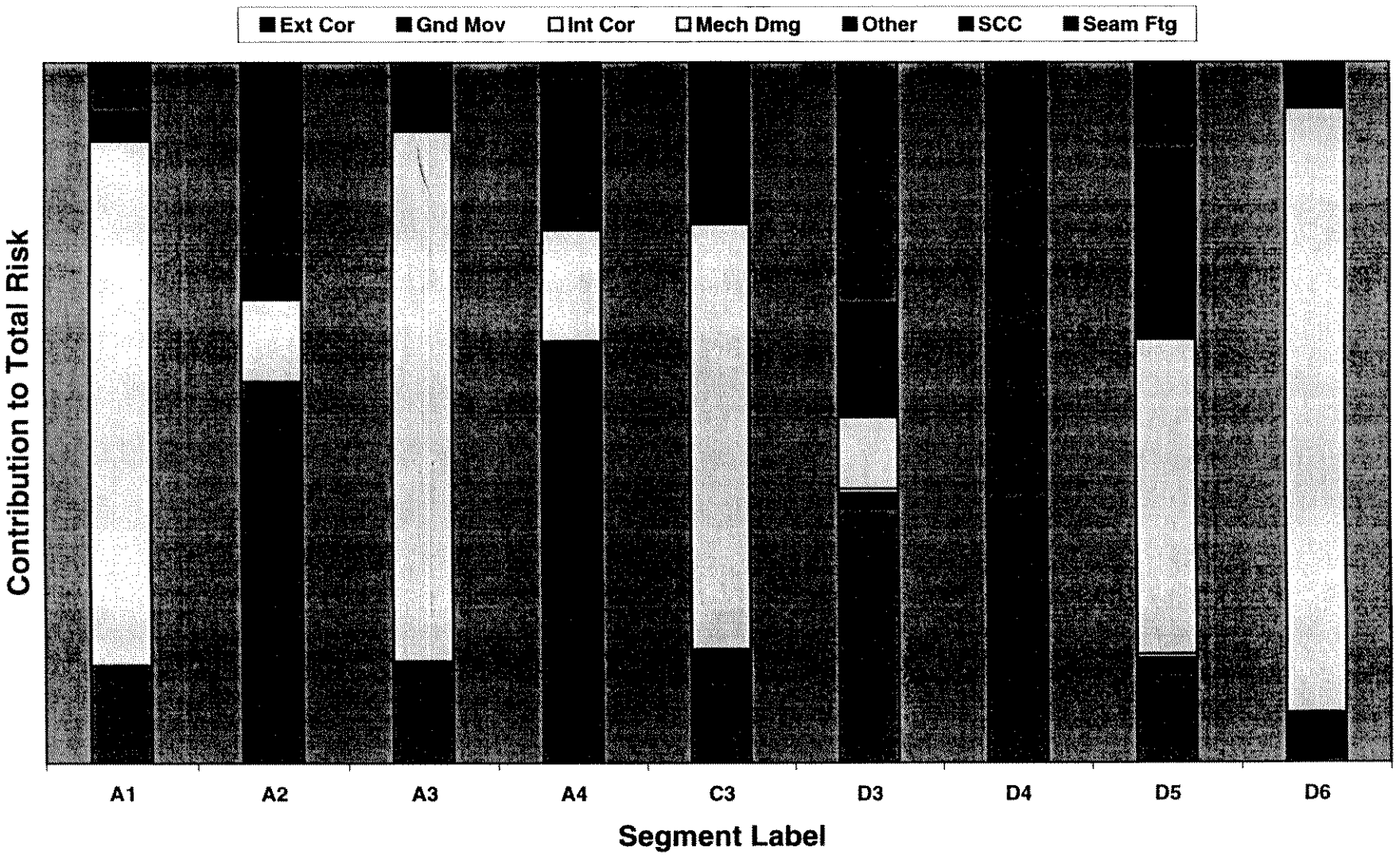
Model Output for On Shore Gas Pipelines

Risk Ranking and Cause Breakdown (small diameter lines)

Risk Estimate - Small Diameter Lines



Risk Impact by Failure Cause - Small Diameter Lines



Rank	Segment Name	Segment	Total Risk ($/km yr) Combined	Total Risk ($/km yr) Ext Cor	Total Risk ($/km yr) Gnd Mov	Total Risk ($/km yr) Int Cor	Total Risk ($/km yr) Mech Dmg	Total Risk ($/km yr) Other	Total Risk ($/km yr) SCC	Total Risk ($/km yr) Seam Ftg
1		A1	3.20E+04	4.48E+03	2.64E+00	8.56E+00	2.39E+04	1.34E+03	2.30E+03	0.00E+00
8		A2	5.96E+02	3.25E+02	6.56E-02	2.70E-01	6.91E+01	3.57E+01	1.66E+02	0.00E+00
6		A3	1.58E+04	2.26E+03	2.65E+01	8.60E+00	1.19E+04	1.34E+03	2.32E+02	0.00E+00
17		A4	5.39E+01	1.51E+01	1.72E+01	1.15E-01	8.49E+00	1.14E+01	1.53E+00	0.00E+00
9		C3	5.60E+02	6.52E+01	2.52E+01	4.02E-01	3.40E+02	1.29E+02	0.00E+00	0.00E+00
12		D3	8.05E+01	2.90E+01	1.85E+00	5.09E-01	8.38E+00	1.30E+01	2.77E+01	0.00E+00
7		D4	6.71E+03	2.49E+03	2.06E+00	5.26E-01	5.16E+00	1.67E+01	4.19E+03	0.00E+00
18		D5	5.38E+01	6.90E+00	1.10E+00	3.14E-01	2.42E+01	1.45E+01	6.79E+00	0.00E+00
2		D6	2.09E+04	1.21E+02	1.38E+03	1.30E+01	1.80E+04	1.40E+03	0.00E+00	0.00E+00
			Combined	Ext Cor	Gnd Mov	Int Cor	Mech Dmg	Other	SCC	Seam Ftg
1		A1	1.00E+00	1.40E-01	8.25E-05	2.67E-04	7.46E-01	4.17E-02	7.17E-02	0.00E+00
8		A2	1.00E+00	5.45E-01	1.10E-04	4.53E-04	1.16E-01	5.99E-02	2.78E-01	0.00E+00
6		A3	1.00E+00	1.44E-01	1.68E-03	5.46E-04	7.54E-01	8.50E-02	1.47E-02	0.00E+00
17		A4	1.00E+00	2.80E-01	3.20E-01	2.14E-03	1.58E-01	2.11E-01	2.83E-02	0.00E+00
9		C3	1.00E+00	1.17E-01	4.50E-02	7.17E-04	6.07E-01	2.31E-01	0.00E+00	0.00E+00
12		D3	1.00E+00	3.61E-01	2.30E-02	6.32E-03	1.04E-01	1.61E-01	3.44E-01	0.00E+00
7		D4	1.00E+00	3.71E-01	3.07E-04	7.84E-05	7.70E-04	2.49E-03	6.25E-01	0.00E+00
18		D5	1.00E+00	1.28E-01	2.05E-02	5.83E-03	4.49E-01	2.70E-01	1.26E-01	0.00E+00
2		D6	1.00E+00	5.79E-03	6.60E-02	6.22E-04	8.61E-01	6.70E-02	0.00E+00	0.00E+00

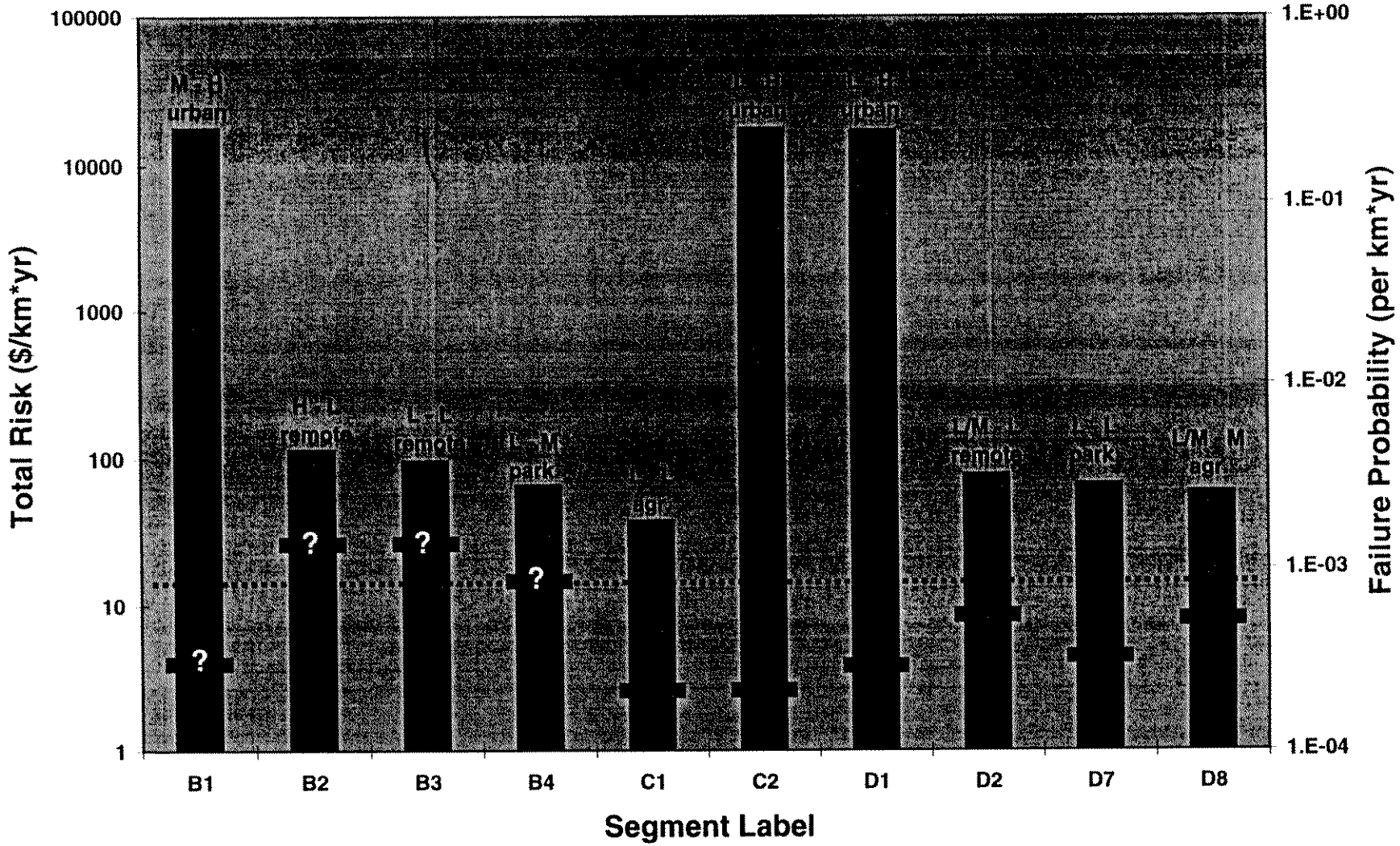
Rank	Segment Name	Segment	Prob. Fail (per km yr) Combined	Prob. Fail (per km yr) Ext Cor	Prob. Fail (per km yr) Gnd Mov	Prob. Fail (per km yr) Int Cor	Prob. Fail (per km yr) Mech Dmg	Prob. Fail (per km yr) Other	Prob. Fail (per km yr) SCC	Prob. Fail (per km yr) Seam Ftg
1		A1	3.18E-03	1.27E-03	1.00E-07	2.43E-06	1.39E-03	2.00E-04	3.18E-04	
8		A2	4.01E-03	2.93E-03	1.00E-07	2.43E-06	1.45E-04	2.00E-04	7.32E-04	
6		A3	1.56E-03	6.40E-04	1.00E-06	2.43E-06	6.87E-04	2.00E-04	3.20E-05	
17		A4	6.89E-04	3.18E-04	1.00E-04	2.43E-06	5.20E-05	2.00E-04	1.59E-05	
9		C3	5.91E-04	1.81E-04	1.00E-05	1.11E-06	1.99E-04	2.00E-04		
12		D3	1.06E-03	5.30E-04	1.00E-05	9.28E-06	4.80E-05	2.00E-04	2.65E-04	
7		D4	6.87E-02	3.42E-02	1.00E-05	7.23E-06	2.67E-05	2.00E-04	3.42E-02	
18		D5	5.08E-04	1.18E-04	5.00E-06	5.36E-06	1.21E-04	2.00E-04	5.90E-05	
2		D6	1.27E-03	3.21E-05	5.00E-05	3.45E-06	9.83E-04	2.00E-04		
			Combined	Ext Cor	Gnd Mov	Int Cor	Mech Dmg	Other	SCC	Seam Ftg
1		A1	1.00E+00	4.00E-01	3.14E-05	7.64E-04	4.36E-01	6.29E-02	1.00E-01	0.00E+00
8		A2	1.00E+00	7.31E-01	2.50E-05	6.07E-04	3.61E-02	4.99E-02	1.83E-01	0.00E+00
6		A3	1.00E+00	4.10E-01	6.40E-04	1.56E-03	4.40E-01	1.28E-01	2.05E-02	0.00E+00
17		A4	1.00E+00	4.62E-01	1.45E-01	3.53E-03	7.55E-02	2.90E-01	2.31E-02	0.00E+00
9		C3	1.00E+00	3.06E-01	1.69E-02	1.89E-03	3.37E-01	3.38E-01	0.00E+00	0.00E+00
12		D3	1.00E+00	4.99E-01	9.41E-03	8.74E-03	4.52E-02	1.88E-01	2.49E-01	0.00E+00
7		D4	1.00E+00	4.98E-01	1.46E-04	1.05E-04	3.88E-04	2.91E-03	4.98E-01	0.00E+00
18		D5	1.00E+00	2.32E-01	9.83E-03	1.05E-02	2.38E-01	3.93E-01	1.16E-01	0.00E+00
2		D6	1.00E+00	2.53E-02	3.94E-02	2.72E-03	7.75E-01	1.58E-01	0.00E+00	0.00E+00

Section F

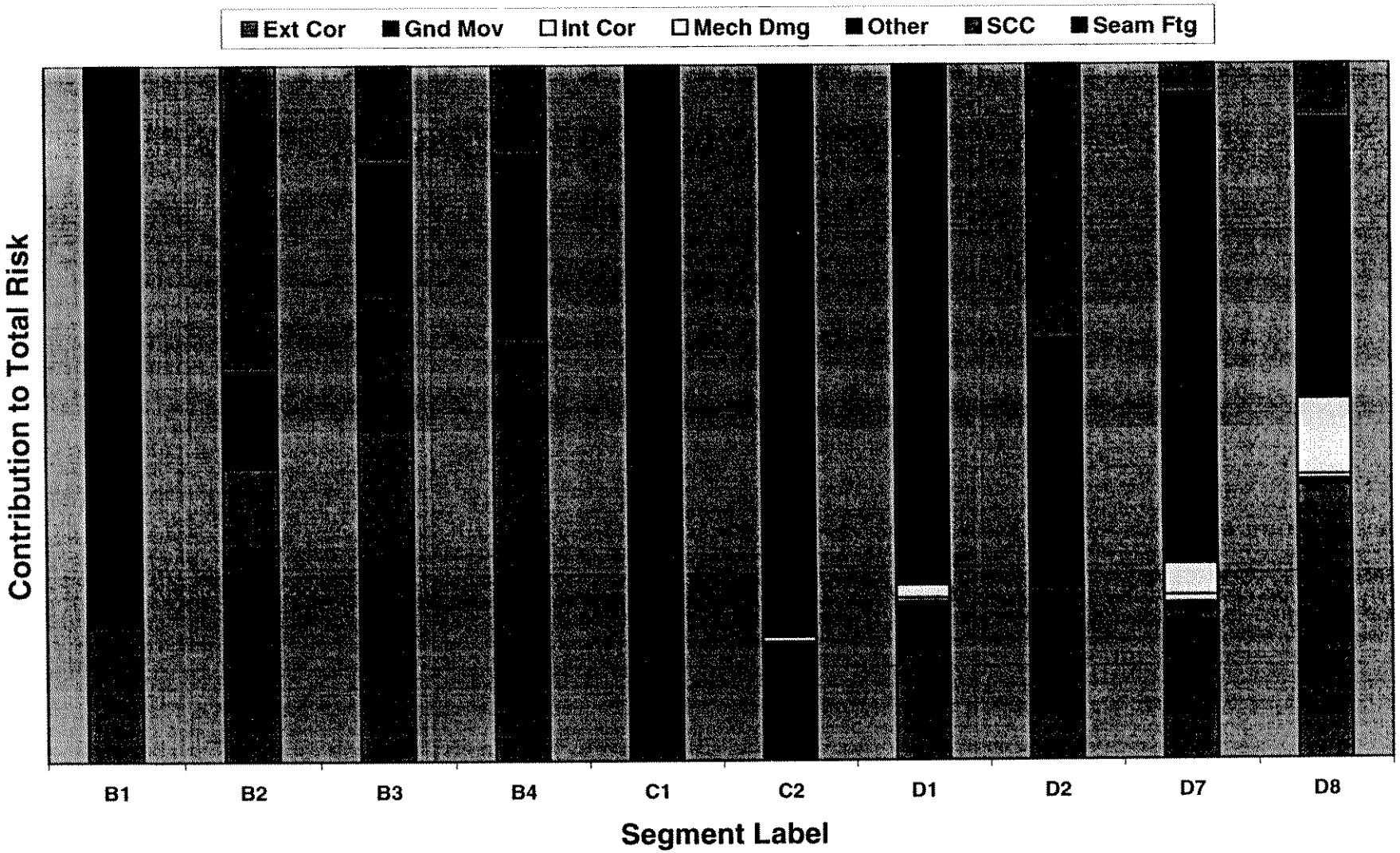
Model Output for On Shore Gas Pipelines

Risk Ranking and Cause Breakdown (large diameter lines)

Risk Estimate - Large Diameter Lines



Risk Impact by Failure Cause - Large Diameter Lines



OnShc st900

Rank	Segment Name	Segment	Total Risk ($/km yr) Combined	Total Risk ($/km yr) Ext Cor	Total Risk ($/km yr) Gnd Mov	Total Risk ($/km yr) Int Cor	Total Risk ($/km yr) Mech Dmg	Total Risk ($/km yr) Other	Total Risk ($/km yr) SCC	Total Risk ($/km yr) Seam Ftg
3		B1	1.78E+04	3.51E+03	2.79E+02	1.61E+01	1.61E+01	1.40E+04	0.00E+00	0.00E+00
10		B2	1.14E+02	4.80E+01	2.42E-01	5.16E-02	3.41E-01	1.53E+01	4.98E+01	0.00E+00
11		B3	9.60E+01	6.47E+01	2.40E+00	5.32E-02	3.39E-01	1.51E+01	1.34E+01	0.00E+00
15		B4	6.58E+01	4.01E+01	2.72E-01	4.07E-02	1.05E-01	1.68E+01	8.44E+00	0.00E+00
19		C1	3.77E+01	3.35E-01	5.75E+00	6.15E-02	3.87E-02	3.15E+01	0.00E+00	0.00E+00
4		C2	1.76E+04	1.05E+02	2.89E+03	1.93E+01	1.39E+02	1.45E+04	0.00E+00	0.00E+00
5		D1	1.71E+04	2.63E+03	1.28E+03	8.92E+01	3.25E+02	1.28E+04	0.00E+00	0.00E+00
13		D2	7.64E+01	1.89E+01	1.50E+00	2.92E-01	2.34E-01	2.54E+01	3.01E+01	0.00E+00
14		D7	6.60E+01	1.41E+01	8.35E-01	7.02E-01	2.96E+00	4.46E+01	2.89E+00	0.00E+00
16		D8	5.88E+01	2.31E+01	4.05E-01	4.29E-01	6.46E+00	2.36E+01	4.77E+00	0.00E+00
			Combined	Ext Cor	Gnd Mov	Int Cor	Mech Dmg	Other	SCC	Seam Ftg
3		B1	1.00E+00	1.97E-01	1.57E-02	9.02E-04	9.05E-04	7.85E-01	0.00E+00	0.00E+00
10		B2	1.00E+00	4.22E-01	2.13E-03	4.54E-04	3.00E-03	1.34E-01	4.38E-01	0.00E+00
11		B3	1.00E+00	6.73E-01	2.50E-02	5.54E-04	3.53E-03	1.58E-01	1.40E-01	0.00E+00
15		B4	1.00E+00	6.09E-01	4.14E-03	6.18E-04	1.59E-03	2.56E-01	1.28E-01	0.00E+00
19		C1	1.00E+00	8.89E-03	1.53E-01	1.63E-03	1.03E-03	8.36E-01	0.00E+00	0.00E+00
4		C2	1.00E+00	5.96E-03	1.64E-01	1.10E-03	7.86E-03	8.21E-01	0.00E+00	0.00E+00
5		D1	1.00E+00	1.53E-01	7.47E-02	5.21E-03	1.90E-02	7.48E-01	0.00E+00	0.00E+00
13		D2	1.00E+00	2.48E-01	1.97E-02	3.82E-03	3.06E-03	3.32E-01	3.94E-01	0.00E+00
14		D7	1.00E+00	2.13E-01	1.26E-02	1.06E-02	4.48E-02	6.75E-01	4.38E-02	0.00E+00
16		D8	1.00E+00	3.93E-01	6.88E-03	7.29E-03	1.10E-01	4.02E-01	8.11E-02	0.00E+00

Rank	Segment Name	Segment	Prob. Fail (per km yr) Combined	Prob. Fail (per km yr) Ext Cor	Prob. Fail (per km yr) Gnd Mov	Prob. Fail (per km yr) Int Cor	Prob. Fail (per km yr) Mech Dmg	Prob. Fail (per km yr) Other	Prob. Fail (per km yr) SCC	Prob. Fail (per km yr) Seam Ftg
3		B1	3.01E-04	9.99E-05	1.00E-06	4.57E-07	9.18E-08	2.00E-04		
10		B2	1.37E-03	7.78E-04	1.00E-06	8.37E-07	1.53E-06	2.00E-04	3.89E-04	
11		B3	1.38E-03	1.06E-03	1.00E-05	8.70E-07	1.53E-06	2.00E-04	1.06E-04	
15		B4	8.59E-04	5.97E-04	1.00E-06	6.06E-07	4.20E-07	2.00E-04	5.97E-05	
19		C1	2.13E-04	2.88E-06	1.00E-05	5.30E-07	7.62E-08	2.00E-04		
4		C2	2.14E-04	2.88E-06	1.00E-05	5.30E-07	7.62E-07	2.00E-04		
5		D1	2.91E-04	8.16E-05	5.00E-06	2.77E-06	2.02E-06	2.00E-04		
13		D2	5.53E-04	1.72E-04	5.00E-06	2.66E-06	8.55E-07	2.00E-04	1.72E-04	
14		D7	3.27E-04	1.05E-04	1.00E-06	5.25E-06	4.99E-06	2.00E-04	1.05E-05	
16		D8	5.27E-04	2.74E-04	1.00E-06	5.08E-06	1.95E-05	2.00E-04	2.74E-05	
			Combined	Ext Cor	Gnd Mov	Int Cor	Mech Dmg	Other	SCC	Seam Ftg
3		B1	1.00E+00	3.31E-01	3.32E-03	1.52E-03	3.05E-04	6.63E-01	0.00E+00	0.00E+00
10		B2	1.00E+00	5.68E-01	7.30E-04	6.11E-04	1.11E-03	1.46E-01	2.84E-01	0.00E+00
11		B3	1.00E+00	7.69E-01	7.26E-03	6.32E-04	1.11E-03	1.45E-01	7.69E-02	0.00E+00
15		B4	1.00E+00	6.95E-01	1.16E-03	7.06E-04	4.89E-04	2.33E-01	6.95E-02	0.00E+00
19		C1	1.00E+00	1.35E-02	4.68E-02	2.48E-03	3.57E-04	9.37E-01	0.00E+00	0.00E+00
4		C2	1.00E+00	1.35E-02	4.67E-02	2.47E-03	3.56E-03	9.34E-01	0.00E+00	0.00E+00
5		D1	1.00E+00	2.80E-01	1.72E-02	9.50E-03	6.95E-03	6.86E-01	0.00E+00	0.00E+00
13		D2	1.00E+00	3.11E-01	9.05E-03	4.81E-03	1.55E-03	3.62E-01	3.11E-01	0.00E+00
14		D7	1.00E+00	3.22E-01	3.06E-03	1.60E-02	1.52E-02	6.11E-01	3.22E-02	0.00E+00
16		D8	1.00E+00	5.20E-01	1.90E-03	9.64E-03	3.70E-02	3.80E-01	5.20E-02	0.00E+00

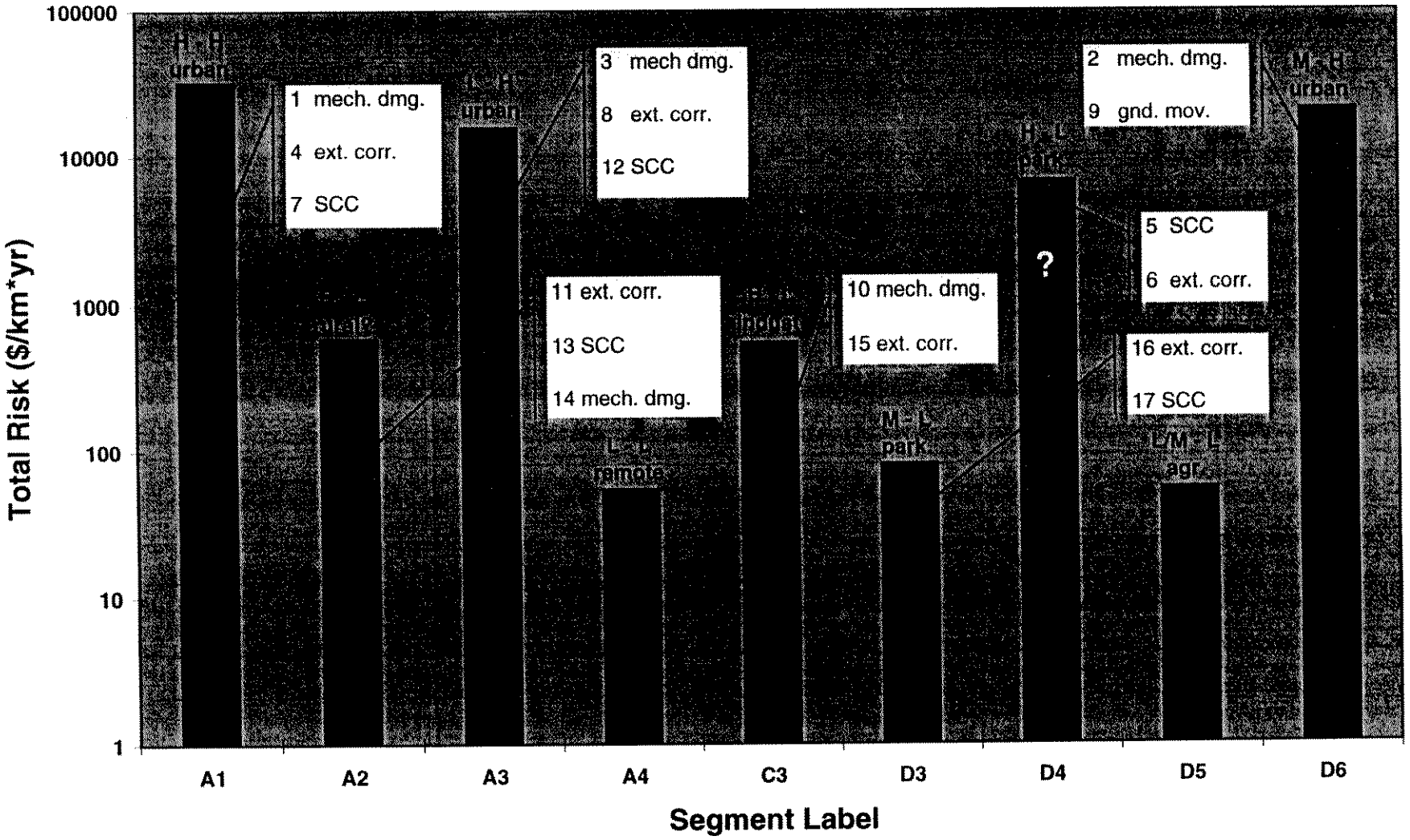
Section G

Model Output for On Shore Gas Pipelines

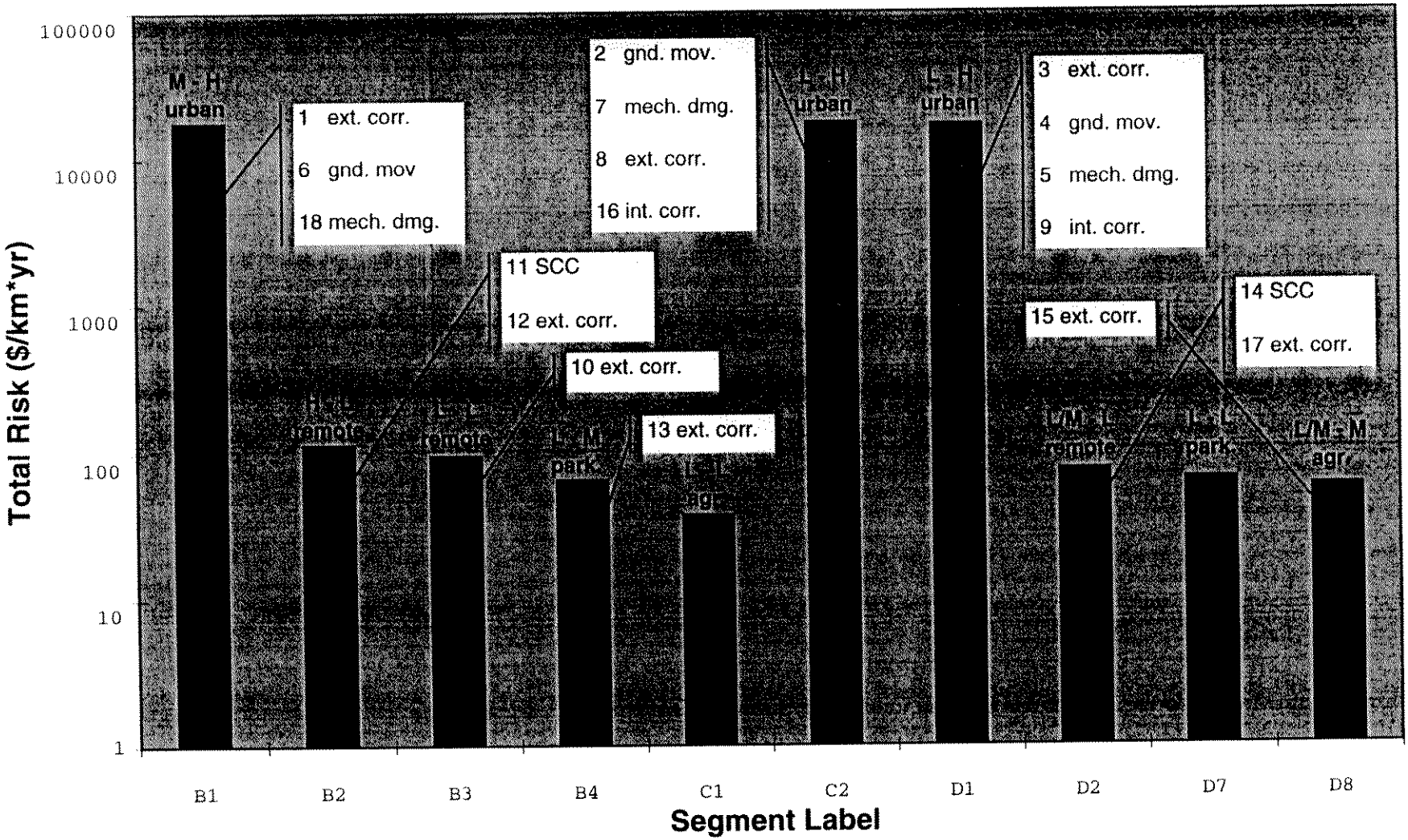
Maintenance Priority Based on Risk Ranking by Failure Cause

C-FER Technologies Inc.

Maintenance Priority - Small Diameter Lines



Maintenance Priority - Large Diameter Lines



Rank	Segment Name	Failure Cause	Segment	Cause	Total Risk ($/km yr)	Prob. Fail (per km yr)	Exp. Cost ($/km yr)	Exp. Fatal. (per km yr)
1		Mechanical Damage	A1	Mech Dmg	2.39E+04	1.39E-03	7.99E+03	7.96E-03
2		Mechanical Damage	D6	Mech Dmg	1.80E+04	9.83E-04	6.01E+03	6.00E-03
3		Other	C2	Other	1.45E+04	2.00E-04	4.75E+03	4.87E-03
4		Other	B1	Other	1.40E+04	2.00E-04	4.58E+03	4.70E-03
5		Other	D1	Other	1.28E+04	2.00E-04	4.19E+03	4.30E-03
6		Mechanical Damage	A3	Mech Dmg	1.19E+04	6.87E-04	4.00E+03	3.94E-03
7		External Corrosion	A1	Ext Cor	4.48E+03	1.27E-03	1.51E+03	1.49E-03
8		Stress Corrosion Cracking	D4	SCC	4.19E+03	3.42E-02	4.19E+03	0.00E+00
9		External Corrosion	B1	Ext Cor	3.51E+03	9.99E-05	1.15E+03	1.18E-03
10		Ground Movement	C2	Gnd Mov	2.89E+03	1.00E-05	9.49E+02	9.73E-04
11		External Corrosion	D1	Ext Cor	2.63E+03	8.16E-05	8.62E+02	8.82E-04
12		External Corrosion	D4	Ext Cor	2.49E+03	3.42E-02	2.49E+03	0.00E+00
13		Stress Corrosion Cracking	A1	SCC	2.30E+03	3.18E-04	7.73E+02	7.63E-04
14		External Corrosion	A3	Ext Cor	2.26E+03	6.40E-04	7.68E+02	7.47E-04
15		Other	D6	Other	1.40E+03	2.00E-04	4.68E+02	4.67E-04
16		Ground Movement	D6	Gnd Mov	1.38E+03	5.00E-05	4.59E+02	4.61E-04
17		Other	A3	Other	1.34E+03	2.00E-04	4.49E+02	4.45E-04
18		Other	A1	Other	1.34E+03	2.00E-04	4.45E+02	4.45E-04
19		Ground Movement	D1	Gnd Mov	1.28E+03	5.00E-06	4.19E+02	4.30E-04
20		Mechanical Damage	C3	Mech Dmg	3.40E+02	1.99E-04	2.46E+02	4.65E-05
21		External Corrosion	A2	Ext Cor	3.25E+02	2.93E-03	2.17E+02	5.44E-05
22		Mechanical Damage	D1	Mech Dmg	3.25E+02	2.02E-06	1.07E+02	1.09E-04
23		Ground Movement	B1	Gnd Mov	2.79E+02	1.00E-06	9.14E+01	9.39E-05
24		Stress Corrosion Cracking	A3	SCC	2.32E+02	3.20E-05	7.88E+01	7.67E-05
25		Stress Corrosion Cracking	A2	SCC	1.66E+02	7.32E-04	1.10E+02	2.79E-05
26		Mechanical Damage	C2	Mech Dmg	1.39E+02	7.62E-07	4.56E+01	4.66E-05
27		Other	C3	Other	1.29E+02	2.00E-04	9.35E+01	1.79E-05
28		External Corrosion	D6	Ext Cor	1.21E+02	3.21E-05	4.08E+01	4.02E-05
29		External Corrosion	C2	Ext Cor	1.05E+02	2.88E-06	3.46E+01	3.53E-05
30		Internal Corrosion	D1	Int Cor	8.92E+01	2.77E-06	2.93E+01	3.00E-05
31		Mechanical Damage	A2	Mech Dmg	6.91E+01	1.45E-04	4.26E+01	1.32E-05
32		External Corrosion	C3	Ext Cor	6.52E+01	1.81E-04	4.79E+01	8.64E-06
33		External Corrosion	B3	Ext Cor	6.47E+01	1.06E-03	6.47E+01	0.00E+00
34		Stress Corrosion Cracking	B2	SCC	4.98E+01	3.89E-04	4.98E+01	0.00E+00
35		External Corrosion	B2	Ext Cor	4.80E+01	7.78E-04	4.80E+01	0.00E+00
36		Other	D7	Other	4.46E+01	2.00E-04	4.46E+01	0.00E+00
37		External Corrosion	B4	Ext Cor	4.01E+01	5.97E-04	4.01E+01	0.00E+00
38		Other	A2	Other	3.57E+01	2.00E-04	2.16E+01	7.08E-06
39		Other	C1	Other	3.15E+01	2.00E-04	2.84E+01	1.51E-06
40		Stress Corrosion Cracking	D2	SCC	3.01E+01	1.72E-04	3.01E+01	0.00E+00

Rank	Segment Name	Failure Cause	Segment	Cause	Total Risk ($/km yr)	Prob. Fail (per km yr)	Exp. Cost ($/km yr)	Exp. Fatal. (per km yr)
41		External Corrosion	D3	Ext Cor	2.90E+01	5.30E-04	2.90E+01	0.00E+00
42		Stress Corrosion Cracking	D3	SCC	2.77E+01	2.65E-04	2.77E+01	0.00E+00
43		Ground Movement	A3	Gnd Mov	2.65E+01	1.00E-06	8.85E+00	8.83E-06
44		Other	D2	Other	2.54E+01	2.00E-04	2.54E+01	0.00E+00
45		Ground Movement	C3	Gnd Mov	2.52E+01	1.00E-05	1.81E+01	3.55E-06
46		Mechanical Damage	D5	Mech Dmg	2.42E+01	1.21E-04	2.30E+01	6.09E-07
47		Other	D8	Other	2.36E+01	2.00E-04	1.96E+01	2.03E-06
48		External Corrosion	D8	Ext Cor	2.31E+01	2.74E-04	2.03E+01	1.39E-06
49		Internal Corrosion	C2	Int Cor	1.93E+01	5.30E-07	6.36E+00	6.49E-06
50		External Corrosion	D2	Ext Cor	1.89E+01	1.72E-04	1.89E+01	0.00E+00
51		Ground Movement	A4	Gnd Mov	1.72E+01	1.00E-04	1.72E+01	0.00E+00
52		Other	B4	Other	1.68E+01	2.00E-04	1.68E+01	0.00E+00
53		Other	D4	Other	1.67E+01	2.00E-04	1.67E+01	0.00E+00
54		Mechanical Damage	B1	Mech Dmg	1.61E+01	9.18E-08	5.28E+00	5.41E-06
55		Internal Corrosion	B1	Int Cor	1.61E+01	4.57E-07	5.27E+00	5.40E-06
56		Other	B2	Other	1.53E+01	2.00E-04	1.53E+01	0.00E+00
57		Other	B3	Other	1.51E+01	2.00E-04	1.51E+01	0.00E+00
58		External Corrosion	A4	Ext Cor	1.51E+01	3.18E-04	1.51E+01	0.00E+00
59		Other	D5	Other	1.45E+01	2.00E-04	1.37E+01	3.94E-07
60		External Corrosion	D7	Ext Cor	1.41E+01	1.05E-04	1.41E+01	0.00E+00
61		Stress Corrosion Cracking	B3	SCC	1.34E+01	1.06E-04	1.34E+01	0.00E+00
62		Internal Corrosion	D6	Int Cor	1.30E+01	3.45E-06	4.38E+00	4.32E-06
63		Other	D3	Other	1.30E+01	2.00E-04	1.30E+01	0.00E+00
64		Other	A4	Other	1.14E+01	2.00E-04	1.14E+01	0.00E+00
65		Internal Corrosion	A3	Int Cor	8.60E+00	2.43E-06	2.92E+00	2.84E-06
66		Internal Corrosion	A1	Int Cor	8.56E+00	2.43E-06	2.88E+00	2.84E-06
67		Mechanical Damage	A4	Mech Dmg	8.49E+00	5.20E-05	8.49E+00	0.00E+00
68		Stress Corrosion Cracking	B4	SCC	8.44E+00	5.97E-05	8.44E+00	0.00E+00
69		Mechanical Damage	D3	Mech Dmg	8.38E+00	4.80E-05	8.38E+00	0.00E+00
70		External Corrosion	D5	Ext Cor	6.90E+00	1.18E-04	6.66E+00	1.20E-07
71		Stress Corrosion Cracking	D5	SCC	6.79E+00	5.90E-05	6.54E+00	1.22E-07
72		Mechanical Damage	D8	Mech Dmg	6.46E+00	1.95E-05	5.47E+00	4.95E-07
73		Ground Movement	C1	Gnd Mov	5.75E+00	1.00E-05	5.14E+00	3.02E-07
74		Mechanical Damage	D4	Mech Dmg	5.16E+00	2.67E-05	5.16E+00	0.00E+00
75		Stress Corrosion Cracking	D8	SCC	4.77E+00	2.74E-05	4.21E+00	2.80E-07
76		Mechanical Damage	D7	Mech Dmg	2.96E+00	4.99E-06	2.96E+00	0.00E+00
77		Stress Corrosion Cracking	D7	SCC	2.89E+00	1.05E-05	2.89E+00	0.00E+00
78		Ground Movement	A1	Gnd Mov	2.64E+00	1.00E-07	8.78E-01	8.82E-07
79		Ground Movement	B3	Gnd Mov	2.40E+00	1.00E-05	2.40E+00	0.00E+00
80		Ground Movement	D4	Gnd Mov	2.06E+00	1.00E-05	2.06E+00	0.00E+00

Rank	Segment Name	Failure Cause	Segment	Cause	Total Risk ($/km yr)	Prob. Fail (per km yr)	Exp. Cost ($/km yr)	Exp. Fatal. (per km yr)
81		Ground Movement	D3	Gnd Mov	1.85E+00	1.00E-05	1.85E+00	0.00E+00
82		Stress Corrosion Cracking	A4	SCC	1.53E+00	1.59E-05	1.53E+00	0.00E+00
83		Ground Movement	D2	Gnd Mov	1.50E+00	5.00E-06	1.50E+00	0.00E+00
84		Ground Movement	D5	Gnd Mov	1.10E+00	5.00E-06	1.02E+00	3.92E-08
85		Ground Movement	D7	Gnd Mov	8.35E-01	1.00E-06	8.35E-01	0.00E+00
86		Internal Corrosion	D7	Int Cor	7.02E-01	5.25E-06	7.02E-01	0.00E+00
87		Internal Corrosion	D4	Int Cor	5.26E-01	7.23E-06	5.26E-01	0.00E+00
88		Internal Corrosion	D3	Int Cor	5.09E-01	9.28E-06	5.09E-01	0.00E+00
89		Internal Corrosion	D8	Int Cor	4.29E-01	5.08E-06	3.77E-01	2.59E-08
90		Ground Movement	D8	Gnd Mov	4.05E-01	1.00E-06	3.24E-01	4.05E-08
91		Internal Corrosion	C3	Int Cor	4.02E-01	1.11E-06	2.95E-01	5.32E-08
92		Mechanical Damage	B2	Mech Dmg	3.41E-01	1.53E-06	3.41E-01	0.00E+00
93		Mechanical Damage	B3	Mech Dmg	3.39E-01	1.53E-06	3.39E-01	0.00E+00
94		External Corrosion	C1	Ext Cor	3.35E-01	2.88E-06	3.13E-01	1.10E-08
95		Internal Corrosion	D5	Int Cor	3.14E-01	5.36E-06	3.03E-01	5.45E-09
96		Internal Corrosion	D2	Int Cor	2.92E-01	2.66E-06	2.92E-01	0.00E+00
97		Ground Movement	B4	Gnd Mov	2.72E-01	1.00E-06	2.72E-01	0.00E+00
98		Internal Corrosion	A2	Int Cor	2.70E-01	2.43E-06	1.80E-01	4.51E-08
99		Ground Movement	B2	Gnd Mov	2.42E-01	1.00E-06	2.42E-01	0.00E+00
100		Mechanical Damage	D2	Mech Dmg	2.34E-01	8.55E-07	2.34E-01	0.00E+00
101		Internal Corrosion	A4	Int Cor	1.15E-01	2.43E-06	1.15E-01	0.00E+00
102		Mechanical Damage	B4	Mech Dmg	1.05E-01	4.20E-07	1.05E-01	0.00E+00
103		Ground Movement	A2	Gnd Mov	6.56E-02	1.00E-07	3.76E-02	1.40E-08
104		Internal Corrosion	C1	Int Cor	6.15E-02	5.30E-07	5.75E-02	2.02E-09
105		Internal Corrosion	B3	Int Cor	5.32E-02	8.70E-07	5.32E-02	0.00E+00
106		Internal Corrosion	B2	Int Cor	5.16E-02	8.37E-07	5.16E-02	0.00E+00
107		Internal Corrosion	B4	Int Cor	4.07E-02	6.06E-07	4.07E-02	0.00E+00
108		Mechanical Damage	C1	Mech Dmg	3.87E-02	7.62E-08	3.58E-02	1.45E-09
109		Seam Weld Fatigue	A1	Seam Ftg	0.00E+00	0.00E+00	0.00E+00	0.00E+00
110		Seam Weld Fatigue	A2	Seam Ftg	0.00E+00	0.00E+00	0.00E+00	0.00E+00
111		Seam Weld Fatigue	A3	Seam Ftg	0.00E+00	0.00E+00	0.00E+00	0.00E+00
112		Seam Weld Fatigue	A4	Seam Ftg	0.00E+00	0.00E+00	0.00E+00	0.00E+00
113		Stress Corrosion Cracking	B1	SCC	0.00E+00	0.00E+00	0.00E+00	0.00E+00
114		Seam Weld Fatigue	B1	Seam Ftg	0.00E+00	0.00E+00	0.00E+00	0.00E+00
115		Seam Weld Fatigue	B2	Seam Ftg	0.00E+00	0.00E+00	0.00E+00	0.00E+00
116		Seam Weld Fatigue	B3	Seam Ftg	0.00E+00	0.00E+00	0.00E+00	0.00E+00
117		Seam Weld Fatigue	B4	Seam Ftg	0.00E+00	0.00E+00	0.00E+00	0.00E+00
118		Stress Corrosion Cracking	C1	SCC	0.00E+00	0.00E+00	0.00E+00	0.00E+00
119		Seam Weld Fatigue	C1	Seam Ftg	0.00E+00	0.00E+00	0.00E+00	0.00E+00
120		Stress Corrosion Cracking	C2	SCC	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Rank	Segment Name	Failure Cause	Segment	Cause	Total Risk ($/km yr)	Prob. Fail (per km yr)	Exp. Cost ($/km yr)	Exp. Fatal. (per km yr)
121		Seam Weld Fatigue	C2	Seam Ftg	0.00E+00	0.00E+00	0.00E+00	0.00E+00
122		Stress Corrosion Cracking	C3	SCC	0.00E+00	0.00E+00	0.00E+00	0.00E+00
123		Seam Weld Fatigue	C3	Seam Ftg	0.00E+00	0.00E+00	0.00E+00	0.00E+00
124		Stress Corrosion Cracking	D1	SCC	0.00E+00	0.00E+00	0.00E+00	0.00E+00
125		Seam Weld Fatigue	D1	Seam Ftg	0.00E+00	0.00E+00	0.00E+00	0.00E+00
126		Seam Weld Fatigue	D2	Seam Ftg	0.00E+00	0.00E+00	0.00E+00	0.00E+00
127		Seam Weld Fatigue	D3	Seam Ftg	0.00E+00	0.00E+00	0.00E+00	0.00E+00
128		Seam Weld Fatigue	D4	Seam Ftg	0.00E+00	0.00E+00	0.00E+00	0.00E+00
129		Seam Weld Fatigue	D5	Seam Ftg	0.00E+00	0.00E+00	0.00E+00	0.00E+00
130		Stress Corrosion Cracking	D6	SCC	0.00E+00	0.00E+00	0.00E+00	0.00E+00
131		Seam Weld Fatigue	D6	Seam Ftg	0.00E+00	0.00E+00	0.00E+00	0.00E+00
132		Seam Weld Fatigue	D7	Seam Ftg	0.00E+00	0.00E+00	0.00E+00	0.00E+00
133		Seam Weld Fatigue	D8	Seam Ftg	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Section H

General Findings for On Shore Pipelines

Findings - Onshore Prioritization

- **General comments**
  - Reasonableness of risk estimates
    - » rankings obtained are broadly consistent with expectations*
      - high & low probability segments identified
      - high & low consequence areas reflected in risk measure
  - Accuracy issues identified
    - » possible concerns regarding external corrosion model
    - » revisit definitions for selected line attributes
  - Repeatability issues identified
    - » user difficulties in understanding the meaning of selected quantitative (objective) line attributes
    - » user difficulties in deciding on the appropriate choice for selected qualitative (subjective) line attributes

** preliminary assessment, subject to participant review*

Accuracy Issues - Onshore Prioritization

External corrosion failure rate algorithm

$$r \propto \left[\frac{A}{t} (T + 17.8)^{2.28} \right] F_{SC}\ F_{CP}\ F_{CT}\ F_{CC}\ F_{CS}$$

- operating temperature (T)
  - » review rate estimate sensitivity to temperature
- coating type factor (F_{CT})
  - » review adopted values in light of operator experience
    - good tape coat may be penalized excessively
- coating condition factor (F_{CC}) & coating shielding factor (F_{CS})
  - » address potential overlap (double counting)

Accuracy Issues - Onshore Prioritization

Line attribute definitions

- Land use type
  - » provide more predefined categories
  - » add user-defined categories
- Crossings/special terrain
  - » split apart
  - » add utility crossings
- Transportation distance
  - » redefine as a *service interruption cost multiplier*
  - » consider transmission vs distribution cost issues
    - variable cost (e.g., delivery shortfall) for transmission
    - fixed cost (e.g., re-light) plus variable cost for distribution

Repeatability Issues - Onshore Prioritization

Quantitative line attributes

- **Clarify meaning**
  - Line pressure attributes
    - » Operating pressure (MAOP vs OP)
    - » Pressure range (effective fatigue cycle)
  - Service interruption cost attributes
    - » Line volume (potential to make-up for delivery shortfall)
    - » Billing abatement threshold (interruption cost trigger)
    - » Transportation distance (effectively a toll charge multiplier)
  - Leak detection system attributes
    - » Detectable release volume
    - » Time to leak detection

Repeatability Issues - Onshore Prioritization

Qualitative line attributes

- **Clarify meaning**
  - Seam weld type & joint weld type
    - » provide more predefined categories
    - » more explicit category definitions
  - Ground movement & pipe damage potential
    - » difficult to categorize without special knowledge
    - » redefine damage potential in terms of
      - type of ground movement
      - ground movement extent and/or movement rate
      - soil type

APPENDIX D

Workshop Presentation Material – Onshore Pipeline Systems

Section I

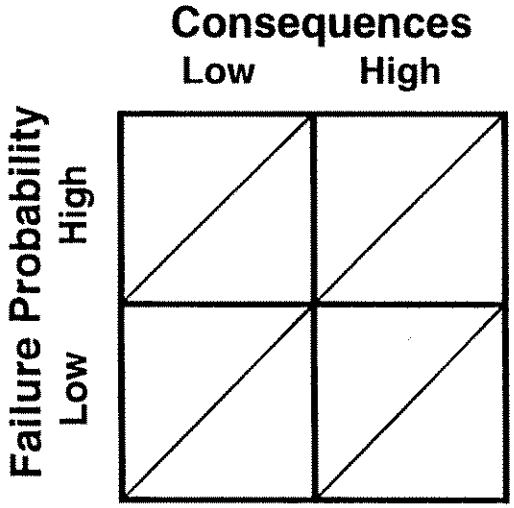
Offshore Pipelines

Validation of *PIRAMID* Prioritization

- **Objectives**
  - Analyze representative pipeline segments
  - Assess degree to which results are consistent with
    - » historical trends
    - » engineering judgement
  - Identify areas for improvement
    - » repeatability of results
      - reduce ambiguity associated with input data
    - » accuracy of results
      - improve accuracy of physical and/or probabilistic models
- **Outcome**
  - Enhanced user confidence
  - Provide input into the planned software updating project

Test Cases - requested

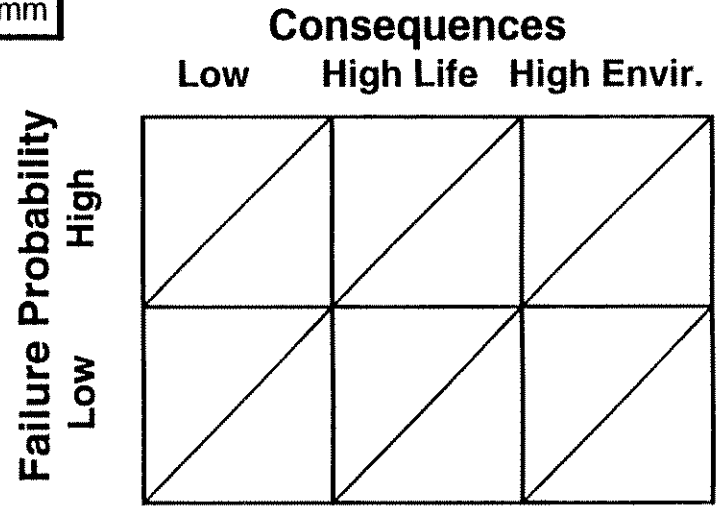
Gas Pipelines



Small 300mm

Large 900mm

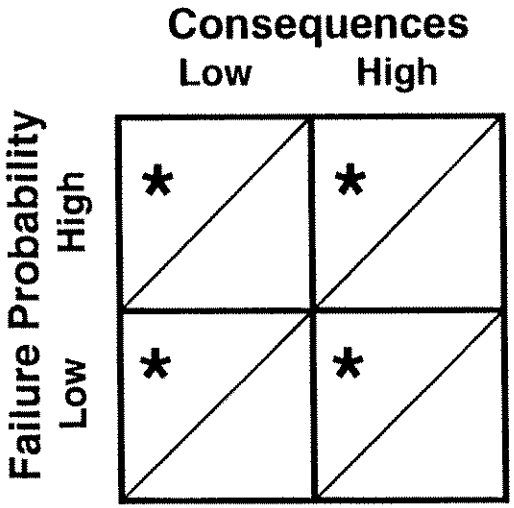
Liquid Pipelines



Test Cases - received

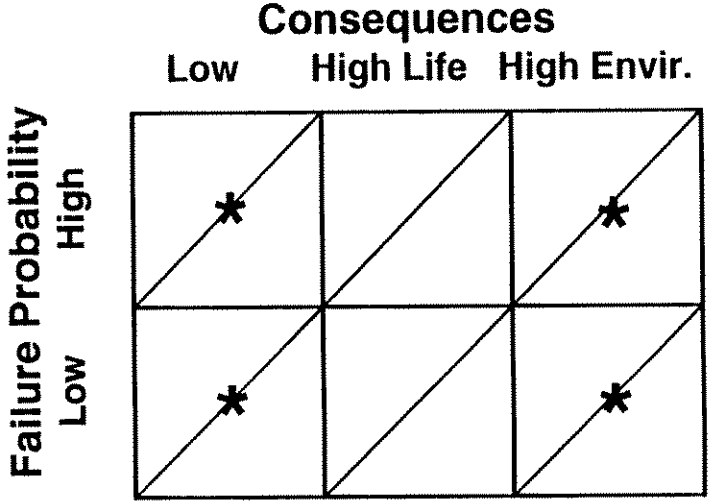
Offshore Pipelines

Gas Pipelines
(MMS)



273 mm Dia. Sour Gas

Liquid Pipelines
(MMS)



508 mm Dia. Crude Oil

Label	Operator	Segment Name	Dia.	Land Use	Probability	Consequence	Comment
S1			273	mixed	L	M	Probability
S2			"	manned platform	M	H	&Conseq.
S3			"	shipping corridor	H	L	Ranking
S4			"	open water	L	L	Assigned
S5			"	unmanned plat.	H	M	by CFER

Results Obtained - offshore gas lines

Pipeline section ranking by

- **Probability of failure** (incidents / km*yr)

- **Expected Cost** ($ / km*yr)
  - » **probability of failure x financial cost given failure**

- **Expected No. of Fatalities** (per km*yr)
  - » **probability of failure x fatalities given failure**

- **Total Risk** ($ / km*yr)
  - » **expected cost + (expected fatalities x λ)**
    - λ is the "societal value of a human life"

No.	Attribute Description	Attribute Name	Units ext (int)	Input Type	Required for Probability Estimation	Required for Consequence Estimation	Analysis Preferences				
							Natural Gas		HVP liquids	LVP liquids included	
							no condensate	w/ condensate	only	consider env.	suppress env.
1	Pipe Diameter	PipeDia	mm (m)	S1	X	X	X	X	X	X	X
2	Pipe Wall Thickness	PipeWall	mm (m)	S1	X	X	X	X	X	X	X
3	Pipe Body Yield Strength	PipeYield	MPa (Pa)	S1	X		X	X	X	X	X
4	Pipe Joint Type	JointType		S2	X		X	X	X	X	X
5	Line Age	LineAge	years	S1	X		X	X	X	X	X
6	Pipe Orientation	Orient	deg (rad)	S1		X	X	X	X	X	X
7	Line Elevation/Depth Profile (-ve sign implies depth)	Elev	m	C1	X	X	X	X	X	X	X
8	Operating Pressure Profile	Press	kPa (Pa)	C1	X	X	X	X	X	X	X
9	Longitudinal Stress Range	StressRange	MPa (Pa)	S1	X		X	X	X	X	X
10	Cumulative Number of Longitudinal Stress Cycles	StressCycle		S1	X		X	X	X	X	X
11	Number of Pipe Free Spans	NSpan	/km (/m)	S1	X		X	X	X	X	X
12	Operating Temperature	LineTemp	°C (K)	S1	X	X	X	X	X	X	X
13	Product Flow Rate (sign denotes flow direction)	FlowRate	kg/s	S1		X	X	X	X	X	X
14	Line Volume (percentage of line capacity)	CapFraction	% (fraction)	S1		X	X	X	X	X	X
15	Billing Abatement Threshold (percentage of nominated volume)	BAT	% (fraction	S1		X	X	X	X	X	X
16	Product Transportation Distance	TransDist	km (m)	S1		X	X	X	X	X	X
17	Block Valve Spacing	ValveSpace	km (m)	S1		X	X	X	X	X	X
18	Time to Block Valve Spacing	TimeClose	min (sec)	S1		X	X	X	X	X	X
19	Detectable Release Volume	VolDetect	cu. m.	S1		X	X	X	X	X	X
20	Time to Leak Detection	TimeDetect	hrs (sec)	S1		X	X	X	X	X	X
21	Time to Leak Stoppage (from time of detection)	TimeStop	hrs (sec)	S1		X	X	X	X	X	X
22	Depth of cover	Cover		S2	X		X	X	X	X	X
23	Vessel Traffic Density	VesselDens		S2	X	X	X	X	X	X	X
24	Subsea Activity	SubSeaAct		S2	X		X	X	X	X	X
25	Seabed Environment Corrosivity	EnvCorrode		S2	X		X	X	X	X	X
26	SCC Potential of Soil Environment	SCCPot		S2	X		X	X	X	X	X
27	External Pipe Coating Type	ExtCoat		S2	X		X	X	X	X	X
28	External Pipe Coating Condition	CoatCond		S2	X		X	X	X	X	X
29	Cathodic Protection Level	CPLevel		S2	X		X	X	X	X	X
30	Product Corrosivity	ProdCorrode		S2	X		X	X	X	X	X
31	Ground Movement Potential	GndMovPot		S2	X		X	X	X	X	X
32	Pipe Fail Potential given Ground Movement	GndFailPot		S2	X		X	X	X	X	X
33	Depth Range (calculated from elevation/depth profile)	DepthRange		S2	X	X	X	X	X	X	X
34	Adjacent Platform Type	PlatType		P1a		X	X	X	X	X	X
	Adjacent Platform Offset	PlatOffset	m	P1b							
35	Spill Trajectory Launch Zones	LaunchZone		S3		X		X		X	X
36	Susceptible Coastal Resources	Resource		P2a		X		X		X	X
	Coastal Resource Shoreline Types	ShoreType		P2b							
37	Coastal Resource Impact Probability	ImpactLoc		P3		X		X		X	X
38	Coastal Resource Impact Time	ImpactTime		P4		X		X		X	X

Attribute Data Input Type

S1 all consecutive sections delineated by KP start & KP end, defined by numeric value
S2 all consecutive sections delineated by KP start & KP end, defined by text string from predefined choice list
S3 all consecutive sections delineated by KP start & KP end, defined by an index value associated with a user defined text string
C1 continuously varying quantity defined by numeric values at KP reference locations
P1 selected locations defined by: a) an index value associated with a text string from a predefined choice list and b) a numeric value
P2 selected locations defined by: a) an index value associated with a user defined text string and b) an index value associated with a text string from a predefined choice list
P3 all user defined locations defined by a numeric value
P4 all user defined locations defined by a probability distribution

Pipeline segment attributes for prioritization

PIRAMID Offshore Prioritization Version 1.5
Model: E:\Userdata\PIPELINE TECH JIP\Risk-Based Optimization\97 Program\Verification\OffShore

MODEL SUMMARY REPORT started Fri Sep 11 09:50:09 1998

##
tem Data

System Title: MMS gas pipeline
Analysis Date: March 1998
Analysis Preferences: Natural Gas (without Environmental assessment)

Baseline Failure Rates:

Failure Cause	Reference Segment Failure Rate (Incidents per km*yr)	Relative Failure Probability Small Leak	Large Leak	Rupture
External Corrosion	0.0001000	0.85	0.10	0.05
Internal Corrosion	0.0004400	0.85	0.10	0.05
Mechanical Damage	0.0001500	0.25	0.50	0.25
Natural Hazard Damage	0.0000800	0.25	0.50	0.25
Ground Movement	N/A	0.20	0.40	0.40
Stress Corrosion Cracking	N/A	0.60	0.30	0.10
Girth Weld Fatigue	N/A	0.60	0.30	0.10
Other	0.0001600	0.80	0.10	0.10

Failure Cause	Reference Segment Scale Factor (Kxx)
External Corrosion	0.0012525
Internal Corrosion	16.333
Mechanical Damage	66.8978
Natural Hazard Damage	30720
Ground Movement	N/A
Stress Corrosion Cracking	N/A
th Weld Fatigue	N/A
er	343

Spill Impact Parameters:

N/A

##
Segment Data

Total Number of Distinct Segments: 5

****
* Pipe Segment #1: [redacted] S1
* Total Length : 20 km (0 km to 20 km)
* Product Type(s): Natural Gas(100% methane)(100%)
****

Section #1: 0km to 1km

Attribute	Value
Pipeline Diameter	237 mm
Pipe Wall Thickness	15.09 mm
Pipe Body Yield Strength	241 MPa
Pipe Joint Type	High Quality Weld
Line Age	1 years
Elevation Profile	-12.3525 m
Product Temperature	21 °C
Pressure Profile	8254.78 kPa
Spanning Stress Range	1e-07 MPa
mulative Number of Stress Cycles	0.1 cycles
oduct Flow Rate	15 kg/s
Block Valve Spacing	20 km
Time to Block Valve Closure	30 min
Detectable Release Volume	200 m³
Time to Leak Detection	24 hr

Time to Leak Stoppage	24 hr
Number of free spans	0 /km
Seabed Environment Corrosivity	Very Low
SCC Potential of Soil Environment	No Potential
External Pipe Coating Type	Poly/Epoxy
External Pipe Coating Condition	Above Average
thodic Protection Level	Above Average
oduct Corrosivity	Negligible (< 0.02 mm/yr)
Depth of Cover	Continuous, Significant Coverage
Ground Movement Potential	Negligible (<= 1 in 100,000/km)
Pipe Damage Potential	Low (<= 1 in 100)
Adjacent Platform Type	Minor Unmanned
Adjacent Platform Offset	0 m
Vessel Traffic Density	Moderate Traffic Density
Subsea Activity	No
Spill Trajectory Launch Zone	N/A
Water Depth Range	Deep (10 to < 60 m)
Pipeline Orientation	0 deg
Line Volume	100 %
Billing Abatement Threshold	100 %
Product Transportation Distance	20 km

Section #2: 1km to 19km

Attribute	Value
Pipeline Diameter	237 mm
Pipe Wall Thickness	15.09 mm
Pipe Body Yield Strength	241 MPa
Pipe Joint Type	High Quality Weld
Line Age	1 years
Elevation Profile	-15.25 m
Product Temperature	21 °C
Pressure Profile	7927.5 kPa
Spanning Stress Range	1e-07 MPa
Cumulative Number of Stress Cycles	0.1 cycles
Product Flow Rate	15 kg/s
Block Valve Spacing	20 km
me to Block Valve Closure	30 min
tectable Release Volume	200 m³
Time to Leak Detection	24 hr
Time to Leak Stoppage	24 hr
Number of free spans	0 /km
Seabed Environment Corrosivity	Very Low
SCC Potential of Soil Environment	No Potential
External Pipe Coating Type	Poly/Epoxy
External Pipe Coating Condition	Above Average
Cathodic Protection Level	Above Average
Product Corrosivity	Negligible (< 0.02 mm/yr)
Depth of Cover	Continuous, Significant Coverage
Ground Movement Potential	Negligible (<= 1 in 100,000/km)
Pipe Damage Potential	Low (<= 1 in 100)
Adjacent Platform Type	None
Adjacent Platform Offset	N/A
Vessel Traffic Density	Moderate Traffic Density
Subsea Activity	No
Spill Trajectory Launch Zone	N/A
Water Depth Range	Deep (10 to < 60 m)
Pipeline Orientation	0 deg
Line Volume	100 %
Billing Abatement Threshold	100 %
Product Transportation Distance	20 km

Section #3: 19km to 20km

Attribute	Value
Pipeline Diameter	237 mm
Pipe Wall Thickness	15.09 mm
Pipe Body Yield Strength	241 MPa
pe Joint Type	High Quality Weld
ine Age	1 years
Elevation Profile	-18.1475 m
Product Temperature	21 °C
Pressure Profile	7600.23 kPa
Spanning Stress Range	1e-07 MPa

Cumulative Number of Stress Cycles	0.1 cycles
Product Flow Rate	15 kg/s
Block Valve Spacing	20 km
Time to Block Valve Closure	30 min
Detectable Release Volume	200 m³
Time to Leak Detection	24 hr
Time to Leak Stoppage	24 hr
Number of free spans	0 /km
Seabed Environment Corrosivity	Very Low
SCC Potential of Soil Environment	No Potential
External Pipe Coating Type	Poly/Epoxy
External Pipe Coating Condition	Above Average
Cathodic Protection Level	Above Average
Product Corrosivity	Negligible (< 0.02 mm/yr)
Depth of Cover	Continuous, Significant Coverage
Ground Movement Potential	Negligible (<= 1 in 100,000/km)
Pipe Damage Potential	Low (<= 1 in 100)
Adjacent Platform Type	Major Manned
Adjacent Platform Offset	0 m
Vessel Traffic Density	Moderate Traffic Density
Subsea Activity	No
Spill Trajectory Launch Zone	N/A
Water Depth Range	Deep (10 to < 60 m)
Pipeline Orientation	0 deg
Line Volume	100 %
Billing Abatement Threshold	100 %
Product Transportation Distance	20 km

Elevation Profile

kilometre post	line elevation (m)
0	-12.2
20	-18.3

Pressure Profile

kilometre post	operating pressure (kPa)
0	8272
20	7583

---------- Probability and Consequence Estimates ----------*

Segment: [redacted] S1
Section #1: 0 km to 1 km

Failure Cause	Failure Probability (incidents/year) Small Leak	Large Leak	Rupture
External Corrosion	0.0000001	0.0000000	0.0000000
Internal Corrosion	0.0000010	0.0000001	0.0000001
Mechanical Damage	0.0001957	0.0003915	0.0001957
Natural Hazard Damage	0.0001539	0.0003078	0.0001539
Ground Movement	0.0000000	0.0000000	0.0000000
Stress Corrosion Cracking	0.0000000	0.0000000	0.0000000
Girth Weld Fatigue	0.0000000	0.0000000	0.0000000
Other	0.0001852	0.0000232	0.0000232
Cost of Failure ($ per incident)	$504500	$1015400	$2075190

Segment: [redacted]
Section #2: 1 km to 19 km

Failure Cause	Failure Probability (incidents/year) Small Leak	Large Leak	Rupture
External Corrosion	0.0000014	0.0000002	0.0000001
Internal Corrosion	0.0000186	0.0000022	0.0000011
Mechanical Damage	0.0003523	0.0007047	0.0003523
Natural Hazard Damage	0.0002770	0.0005540	0.0002770
Ground Movement	0.0000002	0.0000004	0.0000004
Stress Corrosion Cracking	0.0000000	0.0000000	0.0000000
Girth Weld Fatigue	0.0000000	0.0000000	0.0000000
Other	0.0033345	0.0004168	0.0004168
Cost of Failure ($ per incident)	$503601	$1010410	$2058570

Segment: [redacted]

Section #3: 19 km to 20 km

Failure Cause	Failure Probability (incidents/year) Small Leak	Large Leak	Rupture
External Corrosion	0.0000001	0.0000000	0.0000000
[illegible]ternal Corrosion	0.0000010	0.0000001	0.0000001
[illegible]hanical Damage	0.0000196	0.0000391	0.0000196
Natural Hazard Damage	0.0000154	0.0000308	0.0000154
Ground Movement	0.0000000	0.0000000	0.0000000
Stress Corrosion Cracking	0.0000000	0.0000000	0.0000000
Girth Weld Fatigue	0.0000000	0.0000000	0.0000000
Other	0.0001852	0.0000232	0.0000232
Cost of Failure ($ per incident)	$1224650	$5467960	$15615800

****

* Pipe Segment #2: [redacted] S4
* Total Length : 10 km (0 km to 10 km)
* Product Type(s): Natural Gas(100% methane)(100%)

****

Section #1: 0km to 10km

Attribute	Value
Pipeline Diameter	237 mm
Pipe Wall Thickness	15.09 mm
Pipe Body Yield Strength	241 MPa
Pipe Joint Type	High Quality Weld
Line Age	1 years
Elevation Profile	-15.25 m
Product Temperature	21 °C
Pressure Profile	7930 kPa
Spanning Stress Range	1e-07 MPa
Cumulative Number of Stress Cycles	0.1 cycles
Product Flow Rate	15 kg/s
Block Valve Spacing	20 km
[illegible]me to Block Valve Closure	30 min
[illegible]ectable Release Volume	200 m³
Time to Leak [illegible] Detection	24 hr
Time to Leak Stoppage	24 hr
Number of free spans	0 /km
Seabed Environment Corrosivity	Very Low
SCC Potential of Soil Environment	No Potential
External Pipe Coating Type	Poly/Epoxy
External Pipe Coating Condition	Above Average
Cathodic Protection Level	Above Average
Product Corrosivity	Negligible (< 0.02 mm/yr)
Depth of Cover	Continuous, Significant Coverage
Ground Movement Potential	Negligible (<= 1 in 100,000/km)
Pipe Damage Potential	Low (<= 1 in 100)
Adjacent Platform Type	None
Adjacent Platform Offset	N/A
Vessel Traffic Density	Low Traffic Density
Subsea Activity	No
Spill Trajectory Launch Zone	N/A
Water Depth Range	Deep (10 to < 60 m)
Pipeline Orientation	0 deg
Line Volume	100 %
Billing Abatement Threshold	100 %
Product Transportation Distance	20 km

Elevation Profile

kilometre post	line elevation (m)
0	-15.25
10	-15.25

Pressure Profile

[illegible]lometre post	operating pressure (kPa)
[illegible]	7930
10	7930

---------- Probability and Consequence Estimates ----------

Segment: [redacted] S4

Section #1: 0 km to 10 km

Failure Cause	Failure Probability (incidents/year) Small Leak	Large Leak	Rupture
External Corrosion	0.0000008	0.0000001	0.0000000
Internal Corrosion	0.0000103	0.0000012	0.0000006
Mechanical Damage	0.0000196	0.0000391	0.0000196
Natural Hazard Damage	0.0000154	0.0000308	0.0000154
Ground Movement	0.0000001	0.0000002	0.0000002
Stress Corrosion Cracking	0.0000000	0.0000000	0.0000000
Girth Weld Fatigue	0.0000000	0.0000000	0.0000000
Other	0.0018525	0.0002316	0.0002316
Cost of Failure ($ per incident)	$503492	$1005810	$2009740

****

* Pipe Segment #3: [redacted], S2
* Total Length : 1 km (0 km to 1 km)
* Product Type(s): Natural Gas(100% methane)(100%)

****

Section #1: 0km to 1km

Attribute	Value
Pipeline Diameter	237 mm
Pipe Wall Thickness	15.09 mm
Pipe Body Yield Strength	241 MPa
Pipe Joint Type	High Quality Weld
Line Age	1 years
Elevation Profile	-15.3 m
Product Temperature	21 °C
Pressure Profile	7930 kPa
Spanning Stress Range	1e-07 MPa
Cumulative Number of Stress Cycles	0.1 cycles
Product Flow Rate	15 kg/s
Block Valve Spacing	20 km
Time to Block Valve Closure	30 min
Rectable Release Volume	200 m³
Time to Leak Detection	1 hr
Time to Leak Stoppage	24 hr
Number of free spans	0 /km
Seabed Environment Corrosivity	Very Low
SCC Potential of Soil Environment	No Potential
External Pipe Coating Type	Poly/Epoxy
External Pipe Coating Condition	Above Average
Cathodic Protection Level	Above Average
Product Corrosivity	Negligible (< 0.02 mm/yr)
Depth of Cover	Continuous, Significant Coverage
Ground Movement Potential	Negligible (<= 1 in 100,000/km)
Pipe Damage Potential	Low (<= 1 in 100)
Adjacent Platform Type	Major Manned
Adjacent Platform Offset	0 m
Vessel Traffic Density	Moderate Traffic Density
Subsea Activity	Yes
Spill Trajectory Launch Zone	N/A
Water Depth Range	Deep (10 to < 60 m)
Pipeline Orientation	0 deg
Line Volume	100 %
Billing Abatement Threshold	100 %
Product Transportation Distance	20 km

Elevation Profile

kilometre post	line elevation (m)
0	-15.3
1	-15.3

Pressure Profile

kilometre post	operating pressure (kPa)
	7930
1	7930

---------- Probability and Consequence Estimates ----------

Segment: [redacted] S2

Section #1: 0 km to 1 km

Failure Cause	Failure Probability (incidents/year) Small Leak	Large Leak	Rupture
External Corrosion	0.0000001	0.0000000	0.0000000
[illegible]ernal Corrosion	0.0000010	0.0000001	0.0000001
[illegible]hanical Damage	0.0001957	0.0003915	0.0001957
Natural Hazard Damage	0.0001539	0.0003078	0.0001539
Ground Movement	0.0000000	0.0000000	0.0000000
Stress Corrosion Cracking	0.0000000	0.0000000	0.0000000
Girth Weld Fatigue	0.0000000	0.0000000	0.0000000
Other	0.0001852	0.0000232	0.0000232
Cost of Failure ($ per incident)	$1239470	$5569040	$15928900

****

* Pipe Segment #4: [redacted] S1
* Total Length : 1 km (0 km to 1 km)
* Product Type(s): Natural Gas(100% methane)(100%)

****

Section #1: 0km to 1km

Attribute	Value
Pipeline Diameter	237 mm
Pipe Wall Thickness	15.09 mm
Pipe Body Yield Strength	241 MPa
Pipe Joint Type	High Quality Weld
Line Age	25 years
Elevation Profile	-15.3 m
Product Temperature	21 °C
Pressure Profile	7930 kPa
Spanning Stress Range	1e-07 MPa
Cumulative Number of Stress Cycles	0.1 cycles
Product Flow Rate	15 kg/s
Block Valve Spacing	20 km
[illegible]ne to Block Valve Closure	30 min
[illegible]jectable Release Volume	200 m³
Time to Leak Detection	24 hr
Time to Leak Stoppage	24 hr
Number of free spans	0 /km
Seabed Environment Corrosivity	Moderate
SCC Potential of Soil Environment	No Potential
External Pipe Coating Type	Poly/Epoxy
External Pipe Coating Condition	Below Average
Cathodic Protection Level	Below Average
Product Corrosivity	Low (0.02 to 0.1mm/yr)
Depth of Cover	Intermittent or Partial Coverage
Ground Movement Potential	Negligible (<= 1 in 100,000/km)
Pipe Damage Potential	Low (<= 1 in 100)
Adjacent Platform Type	None
Adjacent Platform Offset	N/A
Vessel Traffic Density	High Traffic Density
Subsea Activity	No
Spill Trajectory Launch Zone	N/A
Water Depth Range	Deep (10 to < 60 m)
Pipeline Orientation	0 deg
Line Volume	100 %
Billing Abatement Threshold	100 %
Product Transportation Distance	20 km

Elevation Profile

kilometre post	line elevation (m)
0	-15.3
10	-15.3

Pressure Profile

[illegible]lometre post	operating pressure (kPa)
[illegible]	7930
10	7930

---------- Probability and Consequence Estimates ----------

Segment: [redacted] S1

Section #1: 0 km to 1 km

Failure Cause	Failure Probability (incidents/year) Small Leak	Large Leak	Rupture
External Corrosion	0.0001413	0.0000166	0.0000083
[illegible]ernal Corrosion	0.0001289	0.0000152	0.0000076
[illegible]anical Damage	0.0004894	0.0009787	0.0004894
Natural Hazard Damage	0.0003847	0.0007694	0.0003847
Ground Movement	0.0000000	0.0000000	0.0000000
Stress Corrosion Cracking	0.0000000	0.0000000	0.0000000
Girth Weld Fatigue	0.0000000	0.0000000	0.0000000
Other	0.0001852	0.0000232	0.0000232
Cost of Failure ($ per incident)	$505017	$1072010	$2731340

****

* Pipe Segment #5: [redacted] 55
* Total Length : 1 km (0 km to 1 km)
* Product Type(s): Natural Gas(100% methane)(100%)

****

Section #1: 0km to 1km

Attribute	Value
Pipeline Diameter	237 mm
Pipe Wall Thickness	15.09 mm
Pipe Body Yield Strength	241 MPa
Pipe Joint Type	High Quality Weld
Line Age	25 years
Elevation Profile	-15.3 m
Product Temperature	21 °C
Pressure Profile	7930 kPa
Spanning Stress Range	1e-07 MPa
Cumulative Number of Stress Cycles	0.1 cycles
Product Flow Rate	15 kg/s
Block Valve Spacing	20 km
[illegible]e to Block Valve Closure	30 min
[illegible]ectable Release Volume	200 m³
Time to Leak Detection	1 hr
Time to Leak Stoppage	24 hr
Number of free spans	0 /km
Seabed Environment Corrosivity	Moderate
SCC Potential of Soil Environment	No Potential
External Pipe Coating Type	Poly/Epoxy
External Pipe Coating Condition	Below Average
Cathodic Protection Level	Below Average
Product Corrosivity	Low (0.02 to 0.1mm/yr)
Depth of Cover	Intermittent or Partial Coverage
Ground Movement Potential	Negligible (<= 1 in 100,000/km)
Pipe Damage Potential	Low (<= 1 in 100)
Adjacent Platform Type	Major Unmanned
Adjacent Platform Offset	0 m
Vessel Traffic Density	Moderate Traffic Density
Subsea Activity	Yes
Spill Trajectory Launch Zone	N/A
Water Depth Range	Deep (10 to < 60 m)
Pipeline Orientation	0 deg
Line Volume	100 %
Billing Abatement Threshold	100 %
Product Transportation Distance	20 km

Elevation Profile

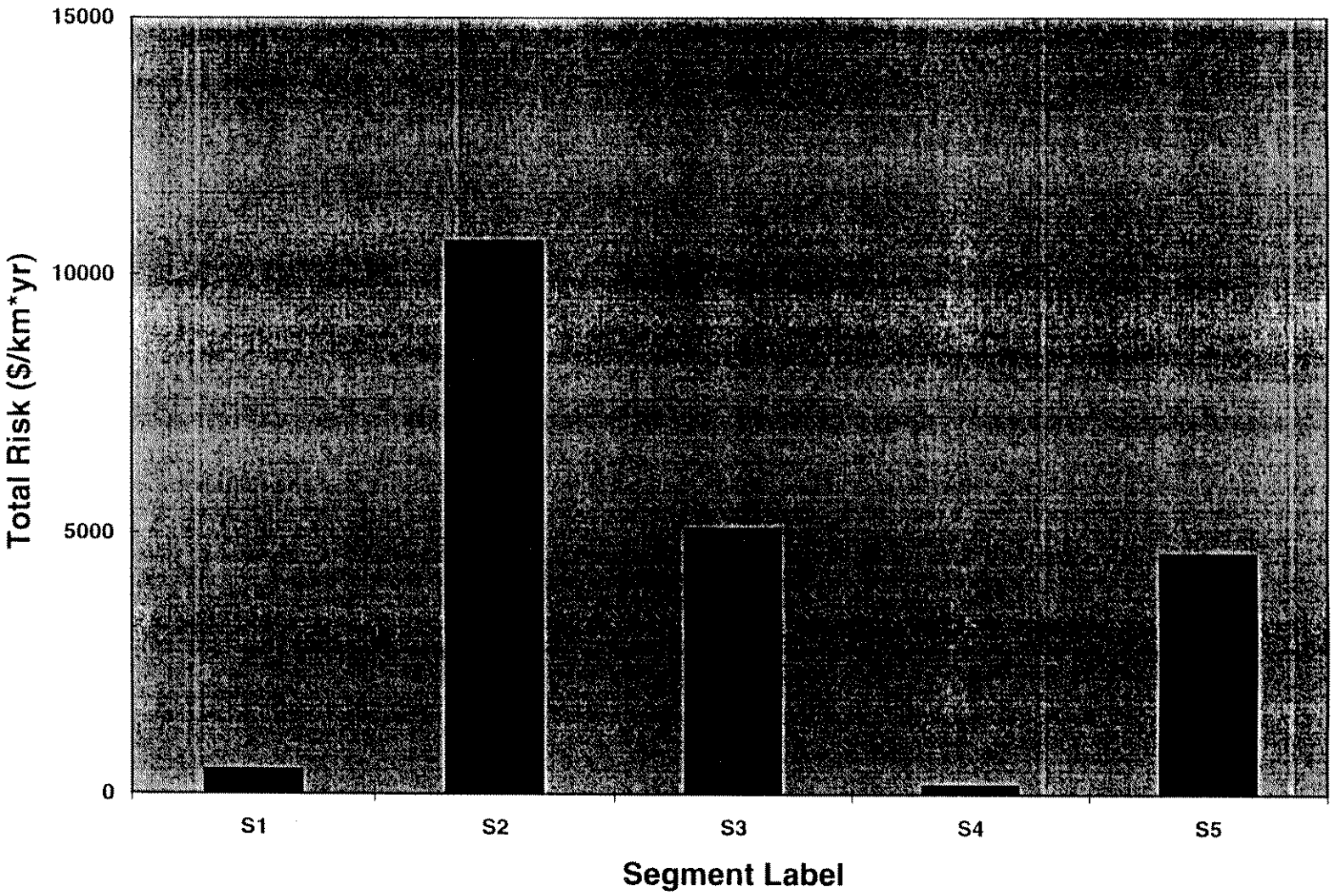
kilometre post	line elevation (m)
0	-15.3
1	-15.3

Pressure Profile

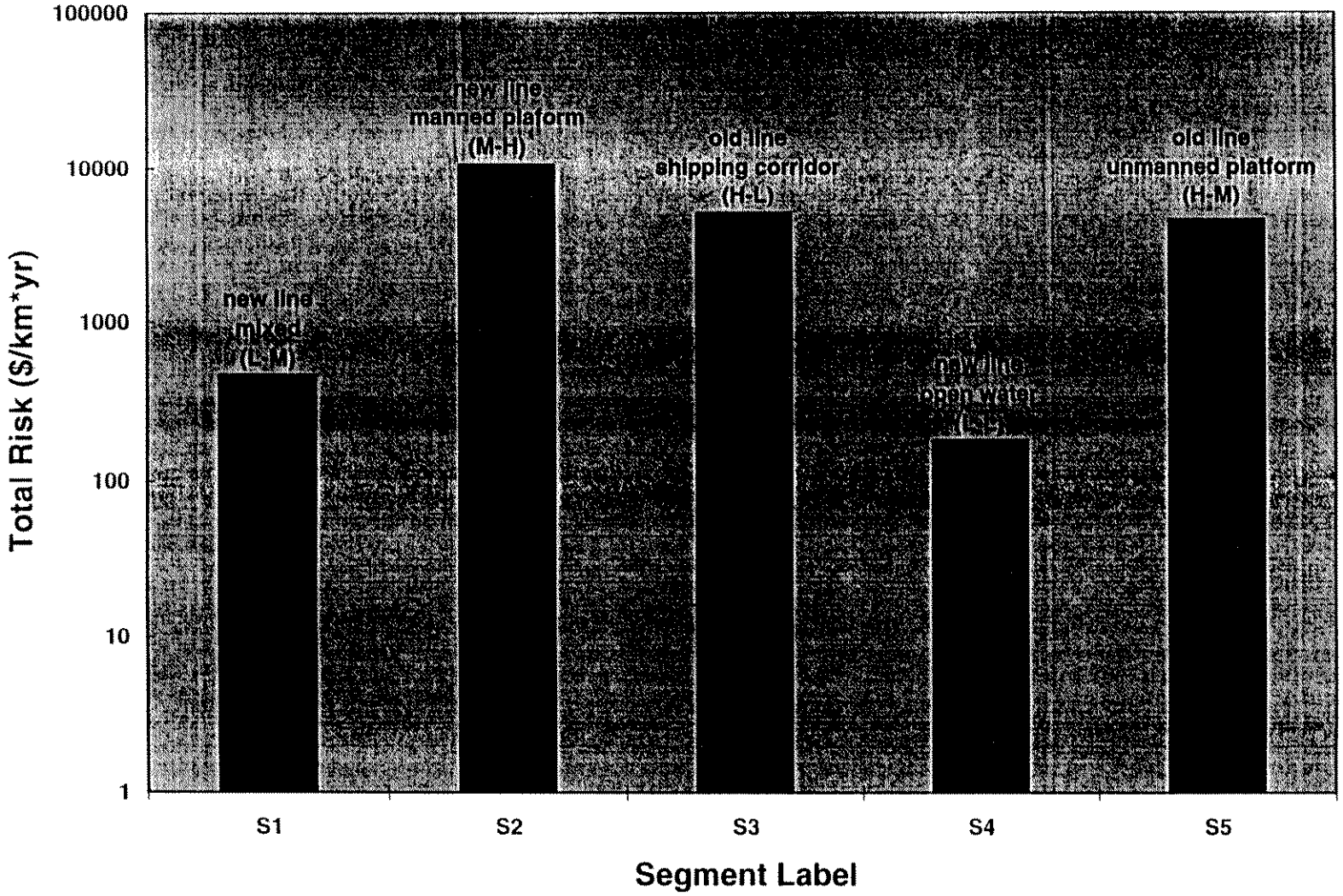
[illegible]ometre post	operating pressure (kPa)
[illegible]	7930
1	7930

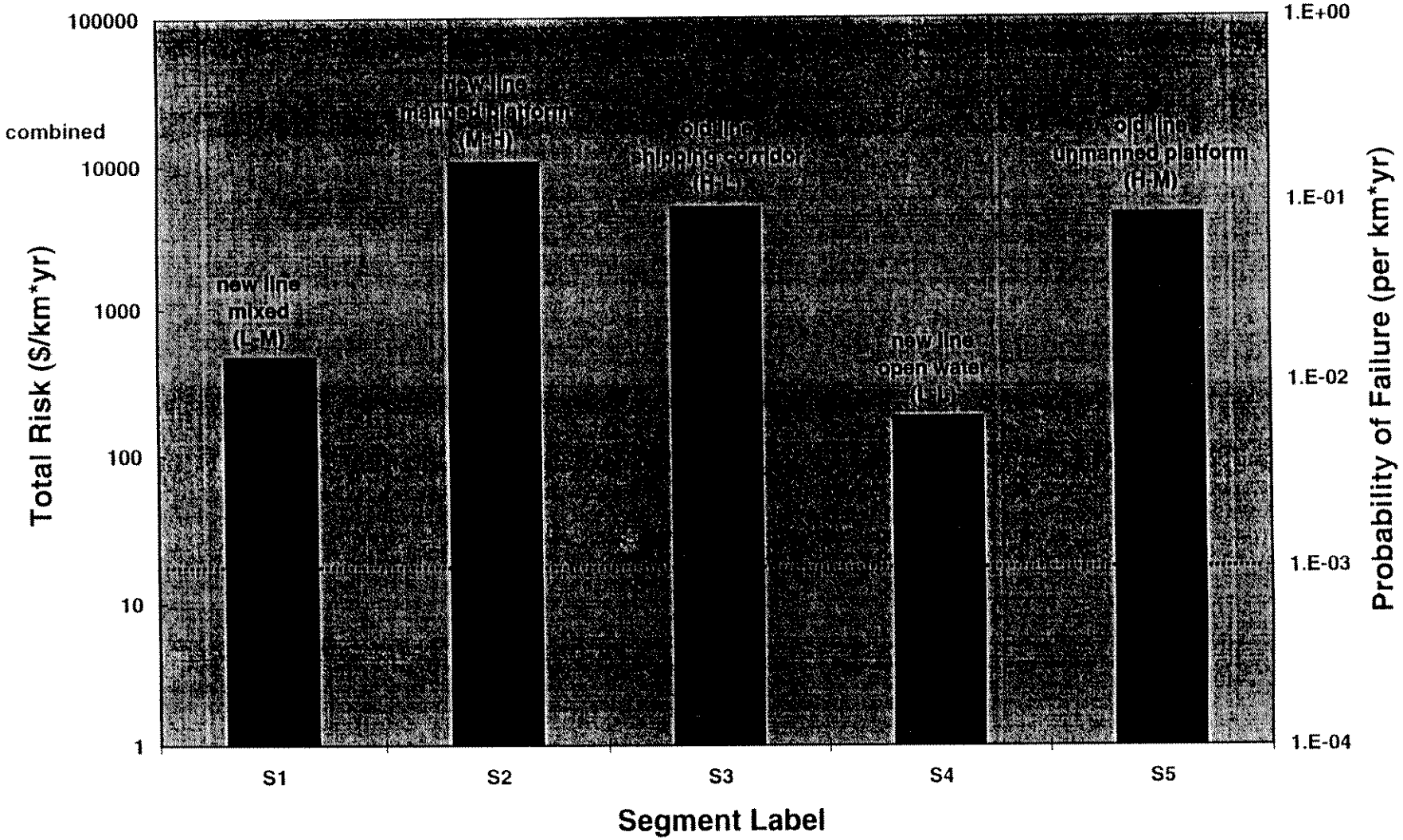
---------- Probability and Consequence Estimates ----------

Segment: [redacted] 55


Total Risk - All Segments
15000
10000
5000
0
Total Risk ($/km*yr)
S1
S2
S3
S4
S5
Segment Label

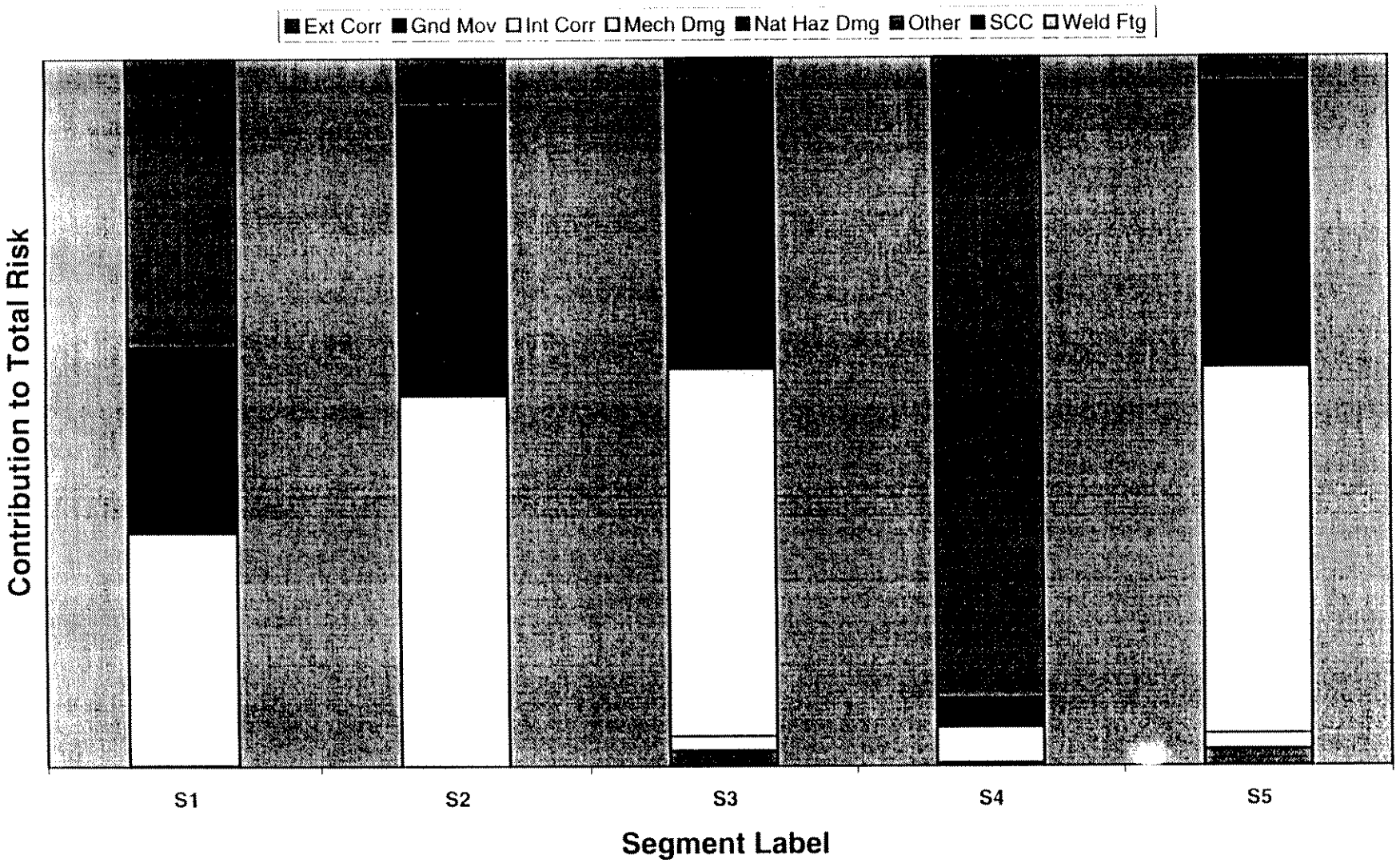
Total Risk - All Segments




Total Risk - All Segments
Total Risk ($/km*yr)
Probability of Failure (per km*yr)
Segment Label
combined
100000
10000
1000
100
10
1
1.E+00
1.E-01
1.E-02
1.E-03
1.E-04
S1
S2
S3
S4
S5
new line
mixed
(L-M)
new line
manned platform
(M-H)
old line
shipping corridor
(H-L)
new line
open water
(L-L)
old line
unmanned platform
(H-M)

Rank	Segment Name	Failure Cause	Segment	Cause	Total Risk ($/km yr)	Prob. Fail (per km yr)	Exp. Cost ($/km yr)	Exp. Fatal. (per km yr)
1		All Causes Combined	S2		1.06E+04	1.63E-03	6.68E+03	1.97E-03
2		All Causes Combined	S3		5.10E+03	4.05E-03	4.86E+03	1.19E-04
3		All Causes Combined	S5		4.59E+03	4.05E-03	4.47E+03	6.05E-05
4		All Causes Combined	S1		4.66E+02	4.36E-04	4.34E+02	1.62E-05
5		All Causes Combined	S4		1.80E+02	2.47E-04	1.80E+02	3.28E-08

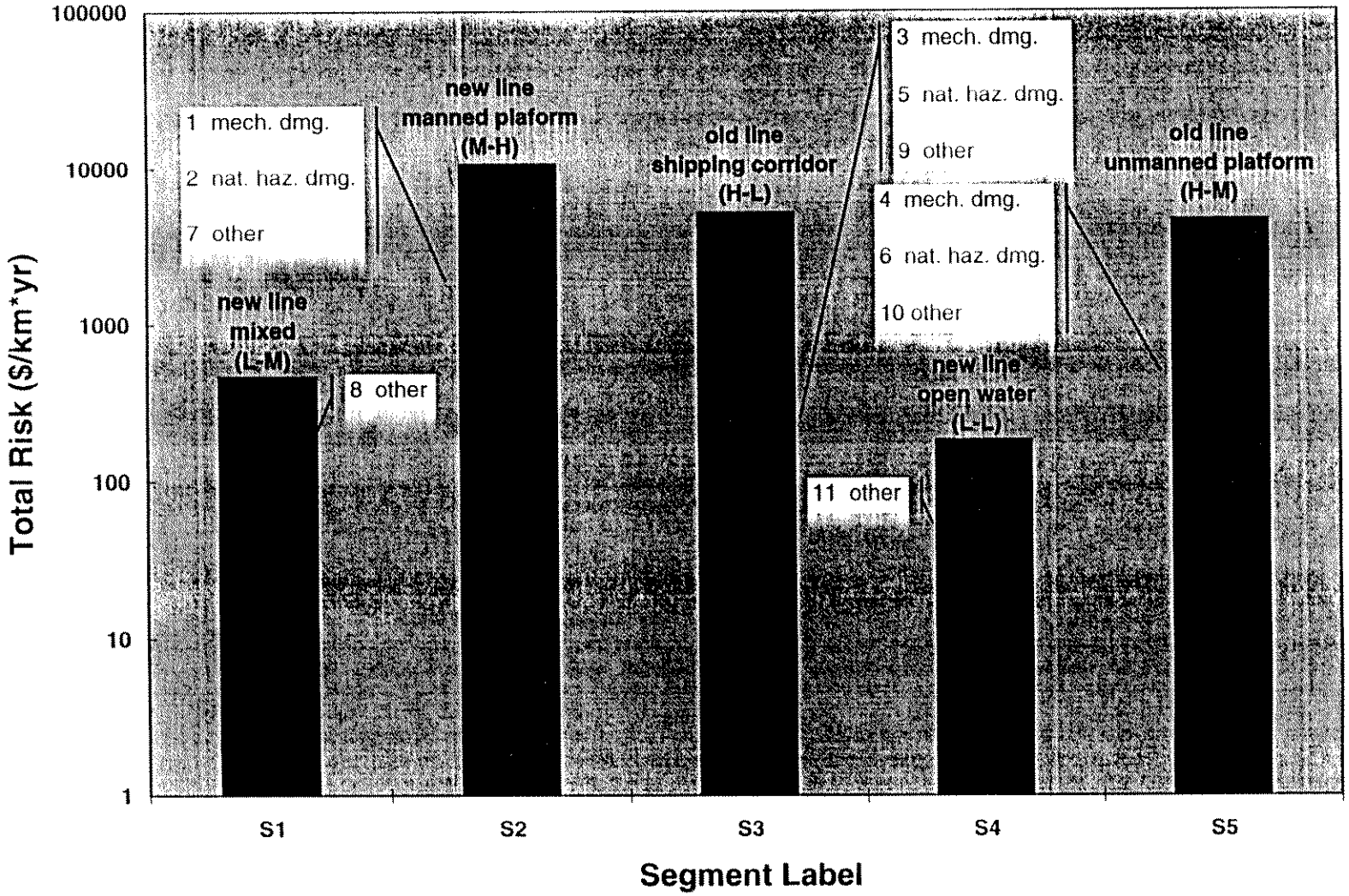
Risk Impact by Failure Cause



Rank	Segment Name	Segment	Total Risk ($/km yr) Combined	Total Risk ($/km yr) Ext Corr	Total Risk ($/km yr) Gnd Mov	Total Risk ($/km yr) Int Corr	Total Risk ($/km yr) Mech Dmg	Total Risk ($/km yr) Nat Haz Dmg	Total Risk ($/km yr) Other	Total Risk ($/km yr) SCC	Total Risk ($/km yr) Weld Ftg
4		S1	4.66E+02	0.06572	0.084813	0.87204	153.05	120.32	191.93	0	0
1		S2	1.06E+04	0.22001	0.44235	2.9194	5540.8	4356.1	727.42	0	0
2		S3	5.10E+03	111.86	0.081117	102.04	2632.9	2069.9	181.62	0	0
5		S4	1.80E+02	0.0575	0.065346	0.76297	8.857	6.9632	163.1	0	0
3		S5	4.59E+03	107.91	0.07	98.44	2358.65	1854.33	169.88	0	0
			Combined	Ext Corr	Gnd Mov	Int Corr	Mech Dmg	Nat Haz Dmg	Other	SCC	Weld Ftg
		S1	1.00E+00	1.41E-04	1.82E-04	1.87E-03	3.28E-01	2.58E-01	4.12E-01	0.00E+00	0.00E+00
		S2	1.00E+00	2.07E-05	4.16E-05	2.75E-04	5.21E-01	4.10E-01	6.84E-02	0.00E+00	0.00E+00
		S3	1.00E+00	2.19E-02	1.59E-05	2.00E-02	5.16E-01	4.06E-01	3.56E-02	0.00E+00	0.00E+00
		S4	1.00E+00	3.20E-04	3.63E-04	4.24E-03	4.93E-02	3.87E-02	9.07E-01	0.00E+00	0.00E+00
		S5	1.00E+00	2.35E-02	1.53E-05	2.14E-02	5.14E-01	4.04E-01	3.70E-02	0.00E+00	0.00E+00

Rank	Segment Name	Segment	Prob. Fail (per km yr) Combined	Prob. Fail (per km yr) Ext Corr	Prob. Fail (per km yr) Gnd Mov	Prob. Fail (per km yr) Int Corr	Prob. Fail (per km yr) Mech Dmg	Prob. Fail (per km yr) Nat Haz Dmg	Prob. Fail (per km yr) Other	Prob. Fail (per km yr) SCC	Prob. Fail (per km yr) Weld Ftg
4		S1	4.36E-04	9.1409E-08	0.00000005	1.2129E-06	0.00011353	8.9256E-05	0.00023156	0	0
1		S2	1.63E-03	9.1409E-08	0.00000005	1.2129E-06	0.00078297	0.00061556	0.00023156	0	0
2		S3	4.05E-03	0.0001662	0.00000005	0.00015161	0.0019574	0.0015389	0.00023156	0	0
5		S4	2.47E-04	9.1409E-08	0.00000005	1.2129E-06	7.8297E-06	6.1555E-06	0.00023156	0	0
3		S5	4.05E-03	0.0001662	0.00000005	0.00015161	0.0019574	0.0015389	0.00023156	0	0
			Combined	Ext Corr	Gnd Mov	Int Corr	Mech Dmg	Nat Haz Dmg	Other	SCC	Weld Ftg
		S1	1.00E+00	2.10E-04	1.15E-04	2.78E-03	2.61E-01	2.05E-01	5.31E-01	0.00E+00	0.00E+00
		S2	1.00E+00	5.60E-05	3.06E-05	7.43E-04	4.80E-01	3.77E-01	1.42E-01	0.00E+00	0.00E+00
		S3	1.00E+00	4.11E-02	1.24E-05	3.75E-02	4.84E-01	3.80E-01	5.72E-02	0.00E+00	0.00E+00
		S4	1.00E+00	3.70E-04	2.03E-04	4.91E-03	3.17E-02	2.49E-02	9.38E-01	0.00E+00	0.00E+00
		S5	1.00E+00	4.11E-02	1.24E-05	3.75E-02	4.84E-01	3.80E-01	5.72E-02	0.00E+00	0.00E+00

Maintenance Priority



Rank	Segment Name	Failure Cause	Segment	Cause	Total Risk ($/km yr)	Prob. Fail (per km yr)	Exp. Cost ($/km yr)	Exp. Fatal. (per km yr)
1		Mechanical Damage	S2	Mech Dmg	5.54E+03	7.83E-04	3.47E+03	1.03E-03
2		Natural Hazard Damage	S2	Nat Haz Dmg	4.36E+03	6.16E-04	2.73E+03	8.13E-04
3		Mechanical Damage	S3	Mech Dmg	2.63E+03	1.96E-03	2.51E+03	6.38E-05
4		Mechanical Damage	S5	Mech Dmg	2.36E+03	1.96E-03	2.29E+03	3.22E-05
5		Natural Hazard Damage	S3	Nat Haz Dmg	2.07E+03	1.54E-03	1.97E+03	5.01E-05
6		Natural Hazard Damage	S5	Nat Haz Dmg	1.85E+03	1.54E-03	1.80E+03	2.53E-05
7		Other	S2	Other	7.27E+02	2.32E-04	4.77E+02	1.25E-04
8		Other	S1	Other	1.92E+02	2.32E-04	1.79E+02	6.41E-06
9		Other	S3	Other	1.82E+02	2.32E-04	1.76E+02	2.82E-06
10		Other	S5	Other	1.70E+02	2.32E-04	1.67E+02	1.53E-06
11		Other	S4	Other	1.63E+02	2.32E-04	1.63E+02	2.82E-08
12		Mechanical Damage	S1	Mech Dmg	1.53E+02	1.14E-04	1.42E+02	5.47E-06
13		Natural Hazard Damage	S1	Nat Haz Dmg	1.20E+02	8.93E-05	1.12E+02	4.30E-06
14		External Corrosion	S3	Ext Corr	1.12E+02	1.66E-04	1.10E+02	1.12E-06
15		External Corrosion	S5	Ext Corr	1.08E+02	1.66E-04	1.06E+02	7.67E-07
16		Internal Corrosion	S3	Int Corr	1.02E+02	1.52E-04	1.00E+02	1.02E-06
17		Internal Corrosion	S5	Int Corr	9.84E+01	1.52E-04	9.70E+01	7.00E-07
18		Mechanical Damage	S4	Mech Dmg	8.86E+00	7.83E-06	8.85E+00	2.55E-09
19		Natural Hazard Damage	S4	Nat Haz Dmg	6.96E+00	6.16E-06	6.96E+00	2.01E-09
20		Internal Corrosion	S2	Int Corr	2.92E+00	1.21E-06	1.96E+00	4.79E-07
21		Internal Corrosion	S1	Int Corr	8.72E-01	1.21E-06	8.24E-01	2.42E-08
22		Internal Corrosion	S4	Int Corr	7.63E-01	1.21E-06	7.63E-01	8.15E-11
23		Ground Movement	S2	Gnd Mov	4.42E-01	5.00E-08	2.75E-01	8.38E-08
24		External Corrosion	S2	Ext Corr	2.20E-01	9.14E-08	1.48E-01	3.61E-08
25		Ground Movement	S1	Gnd Mov	8.48E-02	5.00E-08	7.62E-02	4.33E-09
26		Ground Movement	S3	Gnd Mov	8.11E-02	5.00E-08	7.63E-02	2.40E-09
27		Ground Movement	S5	Gnd Mov	7.00E-02	5.00E-08	7.00E-02	1.07E-09
28		External Corrosion	S1	Ext Corr	6.57E-02	9.14E-08	6.21E-02	1.83E-09
29		Ground Movement	S4	Gnd Mov	6.53E-02	5.00E-08	6.53E-02	2.40E-11
30		External Corrosion	S4	Ext Corr	5.75E-02	9.14E-08	5.75E-02	6.14E-12
31		Stress Corrosion Cracking	S1	SCC	0.00E+00	0.00E+00	0.00E+00	0.00E+00
32		Girth Weld Fatigue	S1	Weld Ftg	0.00E+00	0.00E+00	0.00E+00	0.00E+00
33		Stress Corrosion Cracking	S2	SCC	0.00E+00	0.00E+00	0.00E+00	0.00E+00
34		Girth Weld Fatigue	S2	Weld Ftg	0.00E+00	0.00E+00	0.00E+00	0.00E+00
35		Stress Corrosion Cracking	S3	SCC	0.00E+00	0.00E+00	0.00E+00	0.00E+00
36		Girth Weld Fatigue	S3	Weld Ftg	0.00E+00	0.00E+00	0.00E+00	0.00E+00
37		Stress Corrosion Cracking	S4	SCC	0.00E+00	0.00E+00	0.00E+00	0.00E+00
38		Girth Weld Fatigue	S4	Weld Ftg	0.00E+00	0.00E+00	0.00E+00	0.00E+00
39		Stress Corrosion Cracking	S5	SCC	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40		Girth Weld Fatigue	S5	Weld Ftg	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Findings - Offshore Prioritization

- General comments
  - Reasonableness of risk estimates
    - » rankings obtained are broadly consistent with expectations
      - high & low probability segments identified
      - high & low consequence areas reflected in risk measure
  - Additional work required