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Evaluation of Corrosion Status of a Sour Oil Pipeline

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Summary

In this paper, the integrity of ABC Alberta Ltd.'s Test pipeline is evaluated using the status of 50 corrosion management activities Key Performance Indicators (KPI). The test pipeline has a nominal diameter of 36 inches (914.4 mm) and a length of 35835.92 feet (10.78 KM). This pipeline was constructed in 2010 using API 5L X-70 Carbon Steel. The thickness of this pipeline is 40 mm. The pipeline transports oil effluent along with some gas and water. The H_2S content is 0.5 mol% and the CO_2 content is 0.6 mol%

Analysis of this Test pipeline using software, STEM_Risk_Pipeline™ (version 0.21, License number 1200) indicates that integrity is **Fair (Corrosion Control Score is: 55.41 % and Corrosion Score is: 44.59 %)**.

The conclusion is based on the analysis of the status of the Test pipeline as on 12/2020 based on 5-M methodology (modelling, mitigation, monitoring, maintenance and management). The analysis is based on evaluation of status of 50 key performance indicators (KPI). The scoring of the 50 KPIs and the rational for the score are described in this paper.

1. Pipeline Description

In this paper, the integrity of ABC Alberta Ltd.'s Test pipeline is evaluated using the status of 50 corrosion management activities Key Performance Indicators (KPIs). The status of implementation of each KPI is indicated by score and by color code as shown in Table 1.

Table 1: Status of Implementation

Status of implementation	Score	Color Code
Analysis is not done		Grey
Not relevant	0	Blue
Accounted for adequately	1	Green
Accounted for inadequately	2	Yellowish Green
Accounted for inadequately	3	Yellow
Not adequately accounted for	4	Orange
Not adequately accounted for	5	Red

The test pipeline has a nominal diameter of 36 inches (914.4 mm) and a length of 35835.92 feet (10.78 KM). This pipeline was constructed in 2010 using API 5L X-70 Carbon Steel. The pipeline has no internal coating. The thickness of this pipeline is 40 mm. The pipeline transports oil effluent along with some gas and water. Figure 1 presents the elevation profile of the pipeline.

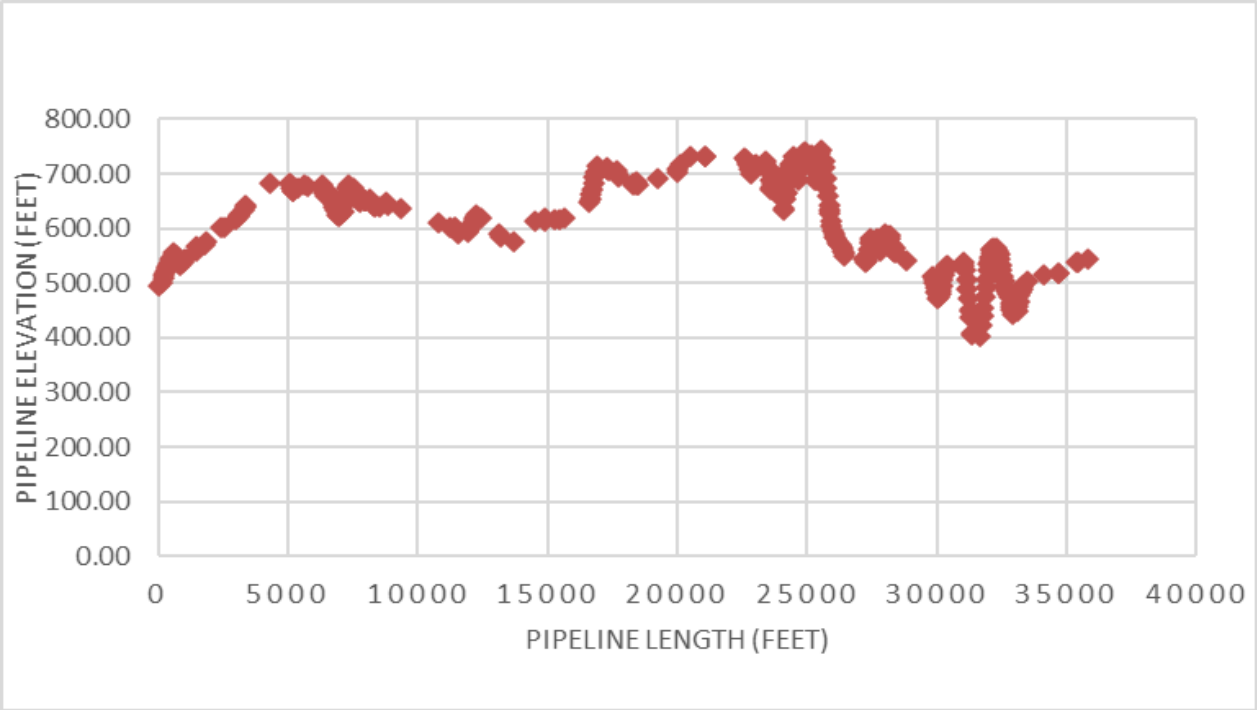

Figure 1: Elevation Profile of the test pipeline

Table 2 outlines the operating parameters of the test pipeline:

Table 2: Operating Parameters

Oil flow rate (BPD)	Water flow rate (BPD)	Gas flow rate (mmscd)	Temp. (°F)	Total Pr. (psi)	pH_2S (mol %)	pCO_2 (mol%)	Sulfate (ppm)	Bicarbonate (ppm)	Chloride (ppm)
2000	10	0.25	80	5000	0.5	0.6	1000	1,000	1000

2. Data and Assumptions

The following data are available for this pipeline:

The pipeline diameter, material, wall thickness, length, elevation profile, temperature, pressure, flow rates, H_2S/CO_2 mole%, elevation profile and date of construction.

The following assumptions are used in this analysis:

1. The pipeline is not segmented and information regarding pipeline segmentation is not available at the time of this report.
2. Corrosion related accessories are properly installed and corrosion professional were involved during the design, commissioning and operation of this pipeline.
3. Since the operation of this pipeline, internal corrosion mitigation strategies are carried out in this pipeline including -pigging, batch inhibition and continuous chemical inhibition. It is assumed that the mitigation strategies are implemented 90% -95% of the time.
4. No internal corrosion monitoring (such as coupons or probes) and no external corrosion monitoring techniques (such as test station) were installed in this pipeline.
5. All the data required for determining the corrosion condition of the segment are not readily available. No validation process of measured data was utilized.
6. The pipeline operating conditions are continuously monitored through SCADA. It is assumed that this pipeline located in an industrial area. Upset conditions in this line will affect the downstream sector. iFILMS has been run for potential upset conditions and are well documented and it is assumed that a communication plan has been established with the downstream team to obtain information in case of upset within the next shift or day.
7. No documented evidence was available regarding conducting proper hydrotest and commissioning of the pipeline
8. The pipeline is protected by Cathodic Protection and annual CP survey reports are available and the effectiveness of CP is 95-99%.
9. ROW Patrol and Leak surveys are conducted above ground.
10. No below ground inspection for measuring external corrosion were carried out.
11. No documented evidence was available regarding hydrotest and commissioning of the pipeline.
12. There is enough workforce trained according to the Integrity Management Plan (IMP) and all personnel involved have at least 5 years of experience and are formally trained.

13. The data from various activities, measurements are manually and systematically transferred in to the database with some human intervention and co-ordination. Internal /external communication strategy is well established and followed.
14. Annual evaluations of all corrosion control activities and scheduled internal audits were conducted and lesson learned were shared within the company
15. There was no failure in this pipeline segment.

3. Context of corrosion control

The results and the rationale for assigning the KPI scores for corrosion control are shown in Table 3.

Table 3: Context of corrosion control

KPI	Description	Score	Rationale for KPI score
1	Sub-division of the infrastructure into segments and its characteristics	5	The pipeline is not segmented and information regarding pipeline segmentation is not available at the time of this report. Hence a KPI score of 5 was assigned.
2	Corrosion mechanisms active in the segment	4	The pipeline transports sour oil effluent with some gas, water and chlorides. Based on iFILMs, the internal corrosion risk is high (1.02 mm/yr) for the pipeline, hence a score of 4 has been assigned. Both external/internal corrosion risks and cracking were considered.
3	Location of infrastructure	4	It is assumed that this pipeline is in an industrial area hence the consequence of failure is considered to be relatively high and a KPI score of 4 has been assigned
4	Overall corrosion risk (Risk times consequence)	4	Considering KPI 2 and 3, the overall corrosion risk is relatively high. Hence a KPI score of 4 has been assigned.
5	Age of infrastructure	2	The line was originally constructed in 2010. Since the pipeline life is 10 years a KPI of 2 has been assigned.

4. Internal corrosion Model

The results and the rationale for assigning the KPI scores for internal corrosion model are shown in Table 4.

Table 4: Internal Corrosion Model

KPI	Description	Score	Rationale for KPI score
6	Material of construction and its basis of selection	1	API 5 L X70 Carbon steel was used to construct the pipeline. It seems to be a correct choice of material. API 5L X70 CS is compatible with sour service, hence, a KPI score of 1 has been assigned.
7	Corrosion allowance	2	The wall thickness of the pipeline is 40 mm. The pipeline was constructed in 2010. Unmitigated Internal corrosion rate established using iFILMS is 1.02 mm/yr and mitigated corrosion rate is 0.09 mm/yr. Assuming that the anticipated life of this pipeline is 60 years, the corrosion allowance is more than the mitigated corrosion rate x anticipated life. Hence a KPI score of 2 has been assigned
8	Normal Operating Conditions	2	Temperature and pressure are constantly measured through SCADA and the system does not go beyond the normal operating conditions for a long time period. Hence a KPI Score of 2 has been assigned.
9	Potential upset conditions in the upstream sector affecting this sector	2	Since this is a gathering line, the operating conditions from upstream pipeline could affect this pipeline. For the purpose of this report it is assumed that the pipeline operating conditions are monitored through SCADA. iFILMS has been run for potential upset conditions and are well understood and it is assumed that a communication plan has been established with the upstream team to obtain information in case of upset within the next shift or day. Hence a score of 2 has been assigned.
10	Potential upset conditions in this sector affecting the downstream sector	2	Upset conditions in this line will affect the downstream sector. For the purpose of this report it is assumed that the pipeline operating conditions are monitored continuously through SCADA. iFILMS has been run for potential upset conditions and are well documented and it is assumed that a communication plan has been established with the downstream team to obtain information in case of upset within the next shift or day. Hence a KPI score of 2 has been assigned

KPI	Description	Score	Rationale for KPI score
11	Corrosion Damage Mechanism (CDM) in the segment	2	Based on iFILMS, this pipeline could have top of the line corrosion (TLC), microbiologically influenced corrosion (MIC) and under-deposit corrosion (UDC). Since the CDMs are established through the software a KPI score of 2 has been assigned
12	Maximum corrosion rate (internal) established and its basis	1	Maximum Internal corrosion rate (1.02 mmyr) was established using iFILMS considering all the corrosion damage mechanisms. Hence a KPI score of 1 has been assigned.
14	Corrosion related accessories and availability of corrosion professional	1	It is assumed that corrosion professional was involved in the design, commissioning and operation stage of the pipeline. Hence related accessories for mitigation, monitoring and maintenance activities were properly installed. Hence a KPI score of 1 has been assigned.
15	Commissioning	4	No documented evidence was available regarding conducting proper hydrotest and commissioning of the pipeline. Hence a KPI score of 4 has been assigned
39	Corrosion rate before and after maintenance activity	1	In general, the corrosion rate should be less after any maintenance activity. Since the established unmitigated corrosion rate is very high, maintenance activities such as pigging, batch chemical inhibition and continuous chemical inhibition are implemented for this pipeline. The corrosion rate after the mitigation activities is calculated to be 0.09 mm/yr. Hence a KPI score of 1 has been assigned.
40	Percentage difference of corrosion rate before and after maintenance activity	0	No corrosion monitoring data is available for comparison at the time of this report, hence this KPI is considered as irrelevant

5. Internal Corrosion Mitigation

The results and the rationale for assigning the KPI scores for internal corrosion mitigation are shown in Table 5.

Table 5: Internal Corrosion Mitigation

KPI	Description	Score	Rationale for KPI score
16	Mitigation to control internal corrosion- is it necessary?	2	Since the established internal corrosion rate for this pipeline is 1.02 mm/yr, it is deemed that this pipeline has severe internal corrosion issues and mitigation activities are required. A KPI score of 2 has been assigned as the mitigation activities are assumed to be carried out on this pipeline since operation.
17	Mitigation strategies to control internal corrosion	2	The mitigation strategies assumed for this pipeline include -pigging, batch inhibition and continuous chemical inhibition. Since the calculated corrosion rate has reduced considerably after the mitigation strategies are implemented, a KPI of 2 has been assigned.
18	Mitigated internal corrosion rate target	2	The targeted mitigated internal corrosion rate is calculated from iFILMS (0.09 mm/yr) based on KPIs 12 and 17 . Since the basis for corrosion rate is by use of a model and not through lab tests, a KPI score of 2 has been assigned
19	Percentage time efficiency of internal corrosion mitigation strategy	3	It is assumed that the mitigation strategies are implemented 90% -95% of the time. Hence KPI score of 3 has been assigned.

6. Internal Corrosion Monitoring

The results and the rationale for assigning the KPI scores for internal corrosion monitoring are shown in Table 6.

Table 6: Internal Corrosion Monitoring

KPI	Description	Score	Rationale for KPI score
24	Internal corrosion monitoring techniques	5	It is assumed that no monitoring techniques were available during the time of this report, hence a KPI score of 5 has been assigned
25	Number of probes per square area to monitor internal corrosion	0	No monitoring techniques were available during the time of this report, hence this KPI is considered as irrelevant
26	Internal corrosion rate from monitoring techniques	0	No monitoring techniques were available during the time of this report, hence this KPI is considered as irrelevant

KPI	Description	Score	Rationale for KPI score
27	Percentage difference between targeted mitigated internal Corrosion rate and corrosion rate from monitoring techniques	0	No monitoring techniques were available during the time of this report, hence this KPI is considered as irrelevant
32	Frequency of corrosion inspection	0	No information regarding inspection were available during the time of this report, hence this KPI is considered as irrelevant
33	Percentage difference between targeted mitigated internal corrosion rate or corrosion rate from monitoring techniques and corrosion rate from inspection technique	0	No monitoring techniques were available during the time of this report, hence this KPI is considered as irrelevant

7. External Corrosion Mitigation

The results and the rationale for assigning the KPI scores for external corrosion mitigation are shown in Table 7.

Table 7: External Corrosion Mitigation

KPI	Description	Score	Rationale for KPI score
20	Mitigation to control external corrosion protection	1	The pipeline is coated with composite and also protected by CP. Hence a score of 1 has been assigned.
21	Type of Mitigation measures to Control External Corrosion	1	The pipeline coating was inspected during installation and CP has been installed from the day of operation.
22	Mitigated External Corrosion Target	0	Mitigated external corrosion targets has not been established for this pipeline. No lab testing has been done to establish target rates. Hence this KPI is considered irrelevant.
23	Effectiveness of Mitigation for External Corrosion	2	It is assumed that the pipeline is protected by CP and annual CP survey reports are available and the effectiveness of CP is 95-99%. Hence a KPI score of 2 is assigned.

8. External Corrosion Model

The results and the rationale for assigning the KPI scores for external corrosion model are shown in Table 8.

Table 8: External Corrosion Model

KPI	Description	Score	Rationale for KPI score
6	External Corrosion protection	1	The pipeline is externally coated with composite which is a corrosion resistant coating and used for rock terrain region. The PL is also protected by Cathodic protection. Hence, a KPI score of 1 has been assigned.
7	Corrosion allowance	5	The wall thickness of the pipeline is 40 mm. The pipeline was constructed in 2010. Mitigated external corrosion rate established using Expedition software is 0.29 mm/yr. Based on Expedition software, as mitigated corrosion rate is significantly less than corrosion allowance x anticipated life (60 years), a KPI score of 5 has been assigned
8	Normal Operating Conditions	2	Temperature and pressure are constantly measured through SCADA. Hence a KPI Score of 2 has been assigned.
9	Potential upset conditions in the upstream sector affecting this sector	2	Potential temperature spikes in the upstream sector could cause coating damage. For the purpose of this report it is assumed that the pipeline operating conditions are monitored through SCADA. It is assumed that a communication plan has been established with the upstream team to obtain information in case of upset within the next shift or day. Hence a score of 2 has been assigned.
10	Potential upset conditions in this sector affecting the downstream sector	2	Potential temperature spikes in this pipeline could cause coating damage. For the purpose of this report it is assumed that the pipeline operating conditions are monitored through SCADA. It is assumed that a communication plan has been established with the downstream team to obtain information in case of upset within the next shift or day Hence a score of 2 has been assigned.
11	Corrosion Damage Mechanism (CDM) in the segment	1	All CDMs has been considered using Expedition software. The expected CMDs are axial gauge corrosion, weld-zone corrosion and abrasion corrosion. Hence a KPI score of 1 has been assigned.
13	Maximum corrosion rate (external) established and its basis	1	Maximum external corrosion rate (0.29mm/yr) was established using Expedition software. Hence a KPI score of 1 has been given

KPI	Description	Score	Rationale for KPI score
14	Corrosion related accessories and availability of corrosion professional	1	It is assumed that corrosion related accessories are installed properly and corrosion professional were involved. Hence a KPI score of 1 has been given.
15	Commissioning	4	No documented evidence was available regarding conducting proper hydrotest and commissioning of the pipeline. Hence a KPI score of 4 has been assigned
41	External corrosion rate before and after maintenance activity	0	There is no information available with respect to the external corrosion rate values specifically measured before and after maintenance activity. Hence this KPI is considered as irrelevant
42	External corrosion rate reduction after maintenance activity	0	This KPI is considered as irrelevant as the corrosion rate after the maintenance activities are not available

9. External Corrosion Monitoring

The results and the rationale for assigning the KPI scores for external corrosion monitoring are shown in Table 9.

Table 9: External Corrosion Monitoring

KPI	Description	Score	Rationale for KPI score
28	External corrosion monitoring techniques	5	No external corrosion monitoring techniques other than annual CP surveys are used in this pipeline, hence a KPI core of 5 has been assigned.
29	Number of probes per square area to monitor External corrosion	0	As no monitoring techniques are available, this KPI is considered to be irrelevant.
30	External corrosion rate from monitoring techniques	0	As no monitoring techniques are available, this KPI is considered to be irrelevant.
31	Percentage difference between targeted mitigated external Corrosion rate and corrosion rate from monitoring techniques	0	As no monitoring techniques are available, this KPI is considered to be irrelevant.
32	Frequency of corrosion inspection	0	No inspection has been carried out on this pipeline. Hence, this KPI is considered to be irrelevant.
34	Percentage difference between targeted mitigated external corrosion rate or corrosion rate from monitoring techniques and corrosion rate from inspection technique	0	As no monitoring techniques are available, this KPI is considered to be irrelevant.

10. Measurement

The results and the rationale for assigning the KPI scores for measurement are shown in Table 10. These 2 KPIs are applicable to both internal and external corrosion

Table 10: Measurement

KPI	Description	Score	Rationale for KPI score
35	Measurement Data Availability	1	It is assumed that all the data required for determining the corrosion condition of the segment is readily available. Hence a KPI Score of 1 has been assigned.
36	Validation of the Measured data	3	No validation process of measured data was carried out. Hence a KPI score of 3 has been assigned

11. Maintenance

The results and the rationale for assigning the KPI scores for maintenance are shown in Table 11.

Table 11: Maintenance

KPI	Description	Score	Rationale for KPI score
37	Procedures for maintenance schedule.	1	Internal corrosion maintenance activities are preventive in nature based on risk reduction and are scheduled. Hence a KPI score of 1 has been assigned.
38	Maintenance activities	1	CP is maintained in the pipeline ad CP surveys are conducted as required. Hence, a KPI score of 1 has been assigned.
43	Workforce Capacity, education and training	1	It is assumed that there is enough workforce trained according to the IMP plan. Hence a KPI score of 1 has been assigned.
44	Workforce Experience, Knowledge and quality	1	It is assumed that all personnel involved have at least 5 years of experience and are formally trained. Hence a KPI score of 1 has been assigned.
45	Data to Database	2	It is assumed that the data from various activities, measurements are manually and systematically transferred in to the database with some human intervention and co-ordination. Hence a KPI score of 2 has been assigned
46	Data from Database	2	Refer to KPI 45
47	Internal Communication Strategy	2	There is an internal communication strategy is established, hence a KPI score of 2 has been assigned
48	External Communication Strategy	2	There is an established external communication strategy in place, hence a KPI score of 2 has been assigned

12. Management

The results and the rationale for assigning the KPI scores for management are shown in Table 12.

Table 12: Management

KPI	Description	Score	Rationale for KPI score
49	Corrosion Management Review	1	It is assumed that annual evaluations of all corrosion control activities and scheduled internal audits were conducted by the EH&S Department. Hence a KPI score of 1 has been assigned.
50	Failure frequency	1	It is assumed that there are no failures in this segment. Hence a KPI score of 1 is assigned

13. Status of KPIs and Risk Quantification

Figure 2 presents the status of corrosion and risk of Test. Among the 50 KPIs, 17 KPIs are adequately implemented, 19 are fairly implemented, 11 are poorly implemented.

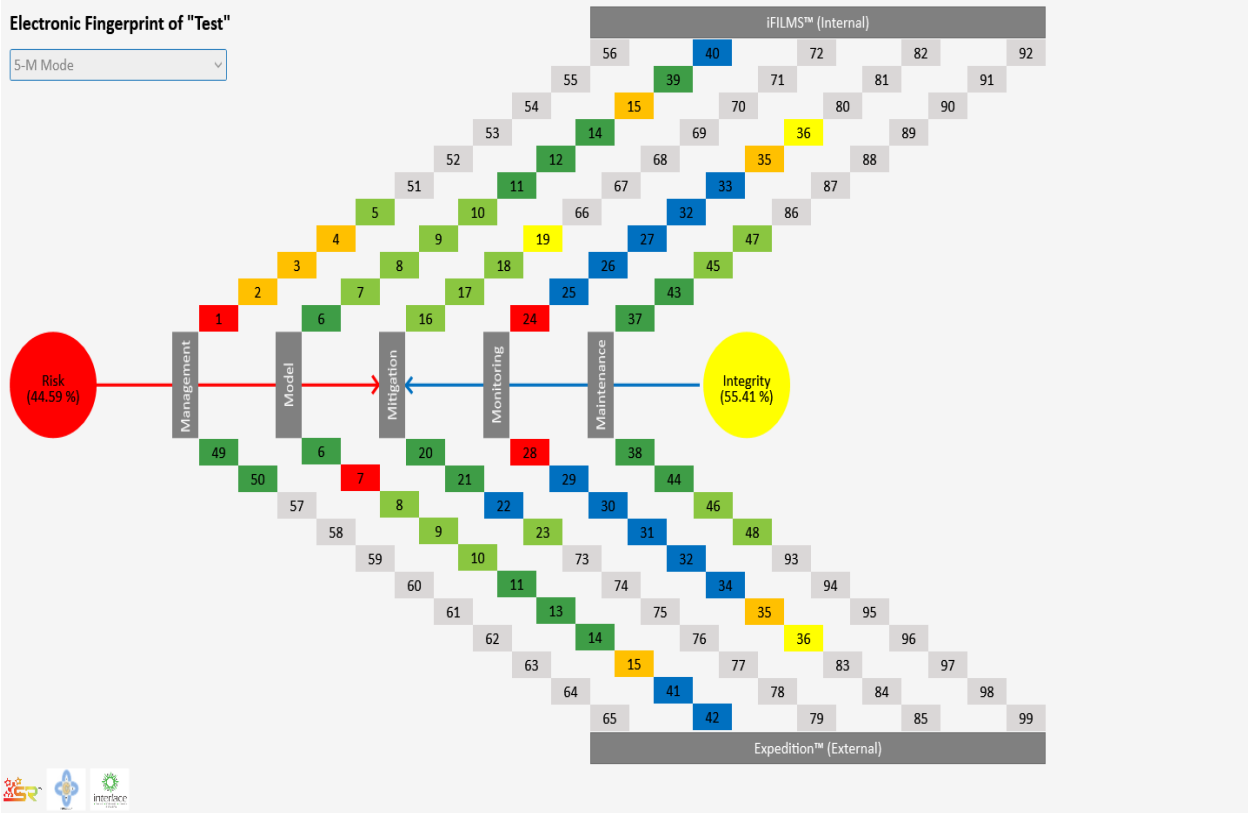

Figure 2: Electronic Fingerprint of Test pipeline as of 06/2020

Figure 3 provides the risk matrix of the Test pipeline. The Test pipeline is deemed to be of moderate risk.

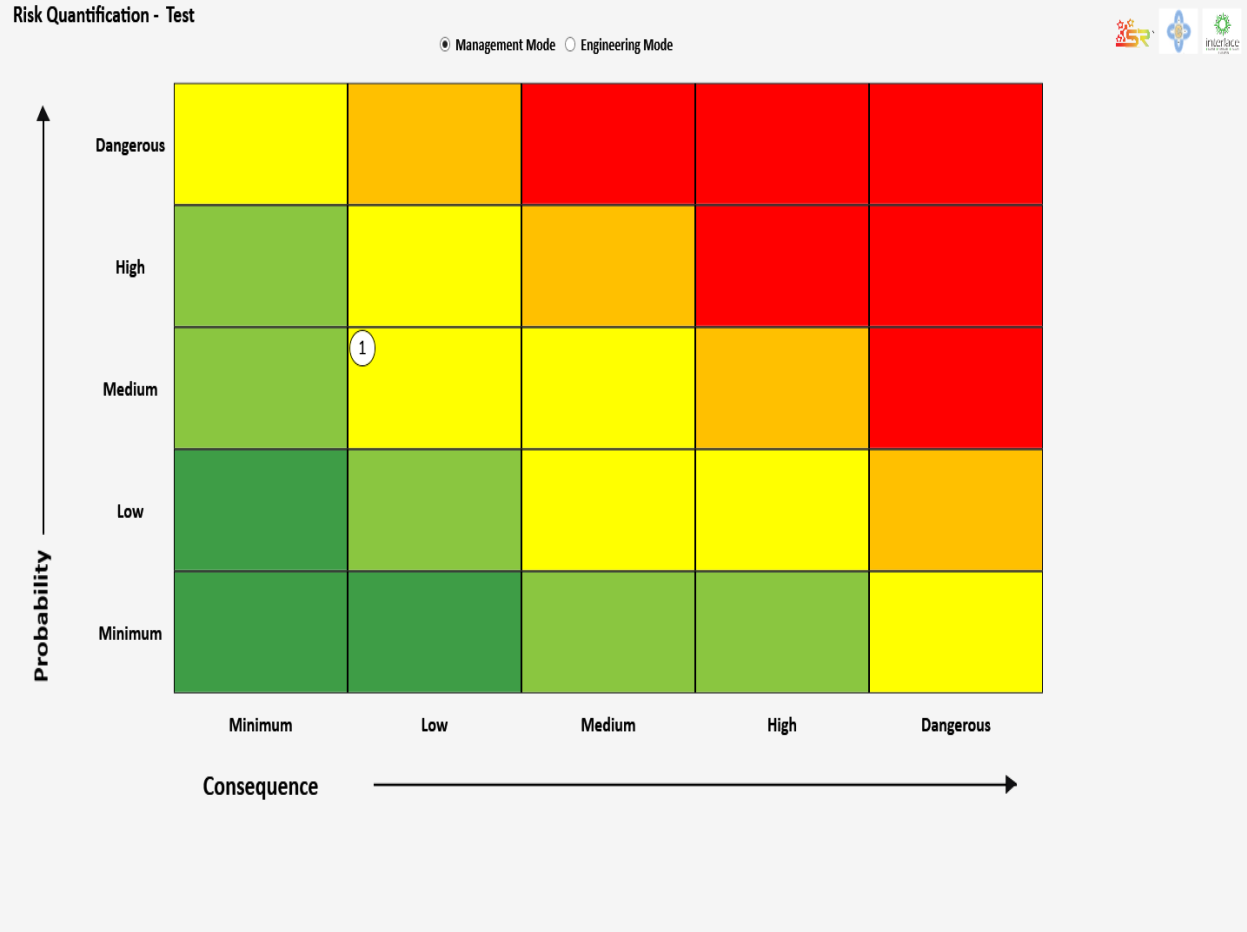

Figure 3: Risk Quantification of Test pipeline as of 06/2020

14. Cost

Based on the cost analysis the operations requested cost for the Test pipeline between 06/2020 and 12/2025 is US ($) 101,807. Expenditure committed between now and 12/2025 is US ($) 55,994. The uncommitted funds available will be US ($) 45,813. This could be allocated for In-line inspections and more below ground inspection for external corrosion monitoring.

14. Recommendations

Based on the above analysis, the following recommendations are suggested to further control corrosion and reduce risk of the pipeline.

1) It is recommended to install internal corrosion monitoring probes such as ER/LPR probes and /or coupons. iFILMS predicted 15 high corrosion areas; Table 13 lists the locations could be used for installation of monitoring equipment.

Table 14: Ideal Locations for Installing Internal Corrosion Monitoring Probes

Pipeline Length (km)	Elevation (m)
5.864	210.7
7.581	224.5
6.949	213.72

2) The Test pipeline is a 36 inch, X-70 pipe with an operating pressure of 5000 psi. The minimum WT required according to Barlow equation for 5000 psi op. pressure and X70 pipeline is 32.5 mm. The corrosion allowance for external corrosion is significantly less than the mitigated corrosion times the anticipated life. In order to increase the integrity score for the Test pipeline, it is recommended to reduce the MOP of this pipeline to 3500 psi.
3) Conduct close interval surveys to determine the effectiveness of CP system on this pipeline.
4) To determine the integrity of external coating on this pipeline, it is recommended to conduct Direct current voltage surveys.
5) Conduct an MFL In line inspection on this pipeline and review the status of this pipeline in 2 years.
6) It is recommended to visually inspect the pipeline coating for any damage during any ILI verification digs.

15. References

1. S. Papavinasam, “Corrosion Control in the Oil and Gas Industry”, (October 2013), Gulf Professional Publication (Imprint of Elsevier), ISBN: 978-0-1239-7022-0. 4.
2. S. Papavinasam, “AIM Corrosion Management: Perfect Key Performance Indicators”, NACE Northern Area Western Conference, Calgary, Alberta, Canada, Feb. 24-25, 2015.

16. Software Report References

1. iFILMS™ Summary
2. Expedition™ Summary
3. STEM_Risk_Pipeline™ - Risk Quantification Report
4. STEM_Risk_Pipeline™ Summary