Quantitative Risk Assessment (QRA) & Leak Detection Criteria (LDC) for an Oil Export Pipeline

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Abstract

A QRA and LDC assessment for an oil export pipeline is presented in this paper. The pipeline is single 200.614km×18' carbon steel pipeline transporting dry sales quality oil from offshore platform to the onshore OGT. The pipeline transverses water depth from 1200m to the shore – with approximately 160km of the pipeline in mid to the shallow water area. The pipeline passes at near proximity to a marine park – which is regarded as sensitive location.

The authors performed a QRA and LDC design for the pipeline. The object of QRA/LDC study is to determine if the current leak detection philosophy excluding the use of statistical leak detection is sufficient, based on QRA results; if not, an appropriate LDC of leak detection system is supposed to be established.

In this paper, risks of three representative sites will be addressed: Mid Portion at KP 100, Near Marine Park at KP 170 and Near Shore at KP 198. A comparison of oil spill volumes with and without LDS has been done to reveal the benefit of taking use of appropriate statistical leak detection. Further more, a sound LDC is defined taking into account regulatory requirement, environmental criteria, and risk assessment involving oil spill, operator response time and current system design.

Keywords: Pipeline, QRA, LDC, LDS, Risk Assessment.

Nomenclature

ALARP =As Low as Reasonably Practicable
ASME =American Society of Mechanical Engineers
API =American Petroleum Institute
CPM =Computational Pipeline Monitoring
CSA =CONTINENTAL SHELF ASSOCIATES, INC
DEP =Design Engineering Practice
DLE =Ductility Level Earthquake
DNV =Det Norske Veritas
DoS =Deployment of surveillance
DSAW =Double Submerged Arc Welded
EARL =East Asia Response Limited
EEA =Economic Exclusive Zone
ERM =Emergency Response Manual
ERT =Emergency Response Team
FBE =Fusion Bonded Epoxy
GSPU =Glass Syntactic Poly Urethane
GUI =Graphical User Interface
HFERW =High Frequency Electric Resistance Welded
HSE =Health and Safety Executive
IP =Institute of Petroleum
KP =Key Point
LD =Leak Detection
LDC =Leak Detection Criteria
LDS =Leak Detection System
MMS = Minerals Management Service (U.S)
OD =Outside Diameter
OGT =Oil and Gas Terminal
OSCP =Oil Spill Contingency Plan
OSSC =Oil Spill Service Centre
PoF =Probability of Failure
POSVCM =Pipeline Oil Spill Volume Calculation Model
QRA =Quantitative Risk Assessment
SCR =Steel Catenary Riser
SLE =Strength Level Earthquake
SMLS =Seamless
SPC =Statistical Process Control
UKOOA=United Kingdom Offshore Operators Association
WT =Wall Thickness

Introduction

The Oil Export Pipeline is single 200.614km×18' carbon steel pipeline transporting dry sales quality oil from offshore platform to onshore OGT. The pipeline transverses water depth from 1200m to the shore – with approximately 160km of the pipeline in mid to the shallow water area. The pipeline passes at near proximity to a marine park – which is regarded as sensitive location.

The QRA study in this paper has referred to Ch. 40 of SPR book from Dr. Bai & Bai [Ref. 2] and its objectives are to evaluate the following:

- To assess the environmental factor/risks associated with oil export through the pipeline and demonstrate that all measures have been undertaken to minimize the risks to ALARP level
- To determine if the current leak detection philosophy excluding the use of statistical leak detection is sufficient – especially in light of the environmentally sensitive area such as Marine Park
- To determine on the additional benefits that the use of statistical leak detection will bring.

The QRA assessment will determine the frequency of leaks, leak volume, response time – in relation to failure probability of the pipeline.

In this paper, risks of three representative site leaks have been addressed: Mid Portion, Near Marine Park and Near Shore. And different hole sizes' leakage (5mm, 10mm 20mm, 50mm, 80mm, and 200mm) at those locations have been calculated. Then, a comparison of oil spill volumes with and without LDS is done to reveal the benefit of taking use of appropriate statistical leak detection.

The QRA results recommended that a pipeline leak detection system is required to be installed. Thus, a further job has been done to define the LDC including the sensitivity, reliability, robustness and accuracy of LDS.

1 Data Summary

Data and parameters used for the Oil Export Pipeline QRA in this report are rich. For example, the pipeline Design and Operating Report has been referred to make the internal corrosion failure frequency calculation and pipeline oil spill modeling; JP Kenney's Marine Hazards Study Report has been consulted to make the PoF assessment. The following are the summary of data employed in this report.

The pipeline design parameters are presented in Table 1 subtracted from the Basis for Design Report

<table>
<tr><th rowspan="2">Segment</th><th colspan="2">KP</th><th>Length</th><th>Water depth</th><th colspan="2">Pipe OD</th><th colspan="2">wall thickness</th><th>Corrosion Allowance</th><th rowspan="2">Grade (API)</th><th rowspan="2">Type</th><th colspan="2">Corrosion coating</th><th colspan="2">Insulation Weight Coating</th></tr>
<tr><th>km</th><th>km</th><th>m</th><th>m</th><th>mm</th><th>inch</th><th>mm</th><th>inch</th><th>mm</th><th>type</th><th>thickness</th><th>type</th><th>thickness</th></tr>
<tr><td>SCR</td><td>0</td><td>1.095</td><td>1095</td><td>1186</td><td rowspan="7">457</td><td rowspan="7">18</td><td>22.2</td><td>0.88</td><td rowspan="3">3</td><td>X70</td><td>SMLS</td><td rowspan="4">FBE</td><td rowspan="4">0.406mm</td><td>GSPU</td><td>50.8m</td></tr>
<tr><td>Deepwater</td><td>1.095</td><td>17.886</td><td>16791</td><td>1186-250</td><td>20.6</td><td>0.81</td><td rowspan="6">X65</td><td>DSAW</td><td>GSPU</td><td>50.8mm</td></tr>
<tr><td>Mid depth trans.</td><td>17.886</td><td>34.443</td><td>16557</td><td>250-91</td><td>20.6</td><td>0.81</td><td>DSAW</td><td>GSPU</td><td>50.8mm</td></tr>
<tr><td rowspan="2">Shallow water</td><td>34.443</td><td>108.72</td><td>74277</td><td>91.0-60.0</td><td>17.5</td><td>0.69</td><td rowspan="4">0</td><td>HFERW</td><td>none</td><td>none</td></tr>
<tr><td>108.72</td><td>198.76</td><td>90036</td><td>60.0-18.0</td><td>17.5</td><td>0.69</td><td>HFERW</td><td rowspan="2">AE</td><td rowspan="2">6mm</td><td>concrete</td><td>50mm</td></tr>
<tr><td rowspan="2">Shore approach</td><td>198.76</td><td>200.6</td><td>18486</td><td>0-18</td><td>20.6</td><td>0.81</td><td>DSAW</td><td>concrete</td><td>50mm</td></tr>
<tr><td>200.6</td><td>200.61</td><td>24.4</td><td>0</td><td>20.6</td><td>0.81</td><td>DSAW</td><td>3LPP</td><td>3mm</td><td>—</td><td>—</td></tr>
</table>

Notes:

1. Density of FBE = 1440 kg/m^3
2. Density of Concrete Weight Coating = 3040 kg/m^3
3. Density of GSPU (Glass Syntactic Polyurethane) = 785 kg/m^3

Table 1: Pipeline Data.

2 QRA by PARLOC Database

1.1 Description of UK PARLOC Databases

The UK PARLOC databases describes studies performed for the United Kingdom Offshore Operators Association (UKOOA), the Institute of Petroleum (IP) and the UK Health and Safety Executive (HSE) regarding loss of containment from offshore pipelines operated in the North Sea and supersedes the last loss of containment study published as PARLOC 2001.

The information for the PARLOC is gained from: Regulatory Authorities, Operators in the UK, Dutch, Norwegian and Danish sectors & the previous PARLOC studies.

There are limitations of the PARLOC database, the database is over 99% complete regarding information on diameter, length, contents and installation dates while the other information such as wall thickness, burial conditions and steel riser type and grade is only 70-90% complete, at the same time the incidents number are relatively small, so the trend of frequency variation by the parameter (such as diameter, length, content) calculated from the PARLOC is not clear in most of the time because of the overlap in confidence intervals.

2.2 Failure Probability Estimation Based on Qualitative Review and UK PARLOC Database

The following is exactly following the PARLOC database, without any modifications to account for the oil field conditions.

Loss of Containment PARLOC Statistics: The total number of pipelines, including both steel and flexible lines, is 1567 at the end of 2000. The total length installed to the end of 2000 is 24,837 km and the operating experience is 328,858 km-yr. 396 incidents occurred to the operating lines in which 248 to pipelines and 148 to fittings. Of the 248 pipeline incidents, 96 leaked to the pipelines including 22 caused by anchor or impact damage, 49 caused by corrosion or material defects and 25 other causes.

Loss of Containment Caused by Corrosion and Material Defects: According to Table 5-8 of PARLOC 2001, there are 74950 years operating experience for oil pipeline longer than 5 km. The number of reported incidents caused by corrosion and material defects is 12. Hence the best estimate of the frequency of loss of containment caused by corrosion and material defects is 1.60x10^{-04} per year. Considering the uncertainties, it was reported by PARLOC 2001 that the lower bound and upper bound for frequency per year is 9.23x10^{-05} and 2.59x10^{-04}, respectively.

Damage Sizes – Equivalent Hole Diameter: Potential hole sizes will be modeled through the use of three representative hole sizes with diameters of 5mm, 10mm 20mm, 50mm, 80mm, and 200mm. The largest hole size considered is 200mm. This is considered to be a conservative upper bound to the equivalent hole size caused by major structural damage to the pipeline. The statistical probability for hole diameter size >80 mm, between 20 and 80 mm and <20 mm is 25%, 18% and 57%, respectively.

3 QRA Assessment

This part predicts the risk of oil spills from the oil export pipeline; determine the frequency of leaks, leak volume, response time – in relation to failure probability of the pipeline. Since the objective of this study is related to leak detection during operating phase, we shall focus on operating risks. PARLOC 2001 database will be used as a start point of the following risk assessment.

The most significant environmental impact from oil spills occurs when the spill reach sensitive shallow waters area and K. Bay. Sensitive coastal resources potentially affected in the region include marine parks and coral clusters. Several hard bottom areas occur along the coastline. Although the pipeline has been routed to avoid live coral areas near the coast, an oil spill from the shallow water pipeline segment could impact several areas of live corals, including a designated Marine Park within hours of the spill or leak.

In the following, specific risk assessment shall be performed for the Oil Export Pipeline and three hypothetical leak sites will be studied: Mid Portion (KP 100), near Marine Park (KP 170) and Near Shore (KP 198). These sites are selected based on their sensitivity and the high potential of impact if leak occurs.

3.1 Hole Sizes & Failure Rates based on PARLOC Database

Representative leaking hole sizes 5mm, 10mm 20mm, 50mm, 80mm, and 200mm. are considered for the entire pipeline. These hole sizes have been selected to provide ease of comparison with the hole sizes considered in the database PARLOC 2001.

Cause	Frequency per km-yr		
	Lower bound	Best Estimate	Upper Estimate
Trawl	2.93E-09	5.85E-08	2.78E-07
Wreck	4.88E-10	9.75E-09	4.63E-08
Anchor	9.76E-10	1.95E-08	9.26E-08
Internal Corrosion	2.83E-07	4.91E-07	7.94E-07
External Corrosion	1.06E-07	1.84E-07	2.98E-07
Material- Weld Defect	3.54E-08	6.14E-08	9.93E-08
Material - Steel Defect	3.54E-08	6.14E-08	9.93E-08

Table 2: Relative failure frequencies

The data contained in the PARLOC database is used as a starting point in the identification of potential hazards and provide initial indications of the likely levels of the loss of containment frequency for an individual pipeline. For different leak causes, the lower bound, best and upper estimate failure frequencies of the 200.614 km long oil export pipeline deriving from PARLOC 2001 (table 5-7 and table 5-8) are list in Table 2.

3.2 Failure Rates Modification from PARLOC Based on Specific Analysis

The failure rates above are exactly statistic results from PARLOC database. However, it should be noted that individual pipelines may have very different histories, properties, characteristics and functions, these values need further modification based on the special conditions of the Oil Export Pipeline.

A Marine Hazards Study has been done, according to which the following marine activities have been considered to threaten the integrity of the Oil Export Pipeline:

- Fisheries activities with the focus on trawling;
- Commercial transport vessels such as cargo and container vessels;

The following sections are detail analysis of the failure rates' modification by different damage causes.

3.2.1 Fishing Interaction

Referring to Marine Hazards Study Report, a trawler density of 2791 per km per year places the concrete coated section of the oil export pipeline in the high frequency class and an impact frequency of 22 per km per year places the non-concrete coated section of the oil export pipeline in the medium frequency class.

The results of trawler impact dent assessment indicate that the permanent dent depth of the non-concrete coated section of the oil export pipeline is within allowable limit based on a medium impact frequency. For the concrete coated section, however, no dent is permitted due to the high impact frequency. However, the impact strength of 50mm thick concrete is estimated to be typically 50kJ, which offers sufficient protection against the trawl impact energy of 1.312kJ.

These results reveal that all the trawl impacts are tolerable. And the oil export pipeline is complete new and no trawling damage has ever been reported in that zone. Thus, trawl caused failure frequency is considered to be negligible in this report.

3.2.2 Merchant Vessels

A shipping lane survey and a risk impact assessment have been performed by JP Kenny. A typical cargo vessel route map figure 3.30 in JP Kenney's Marine Hazard Study Report can show that a typical commercial cargo vessel traveling is confined to within waters on the continental shelf and go across the Oil Export Pipeline at about KP 140.

The impact of drop anchor from commercial cargo vessels on the oil export pipeline was assessed based on methodology outlined in DNV-RP-F107. Combining the calculated energy level at each damage category with the results from Marine Hazards Study Report Table 4.14 and the conditional probability in Table 4.15 yields a failure frequency of $9.6x10^{-6}$ per year. This is within the acceptance criteria of $1.0x10^{-5}$ for high safety class. And the average failure frequency of the whole pipeline (200.614km) is $4.79x10^{-8}$ per km-yr.

According to the typical cargo vessel route map, the main commercial cargo lane is about 25 km away from the Marine Park, so as the mid portion of the pipeline. Obviously, if all ships are run well in the lane, there will be no anchor hazards to the pipeline mid portion or the section near the Marine Park. However, the cargo route we got is just a representative one. Actually, the information on the route of cargo vessels is very limited and not easily obtainable, at least for the vessels registered in Malaysia.

Nevertheless, the exception is in very small proportion; and mid portion of the pipeline is in deeper water, the pipeline section near Marine Park is concrete coated and buried, which will largely release the impact of anchor; the mean leak frequency of anchor caused failure 4.79×10^{-8} per km-yr is taken for mid portion and near Marine Park section of the pipeline. The near shore part of the pipeline is neither near any port nor cargo route. Thus, anchor risk is negligible for this section.

3.2.3 Construction and Material Defects

Verification of the integrity of the pipeline during fabrication can be obtained from pipe mill pressure tests and mill NDT certificates. Verification of the integrity of the pipeline after construction is completed – can be obtained through the gauging plate and pressure testing at pre-commissioning stage. These steps and the overall technical integrity verification plan will significantly reduce the frequency of failure due to material or construction defects for this project.

Based on above, for the oil export pipeline, the frequency of failure due to material and construction defects can be anticipated to be well below 10^{-6} per km-yr. As there is not sufficient information, best estimated results of 1.23×10^{-7} per km-yr from PARLOC 2001 is taken for further assessment.

3.2.4 Sinking and Grounding Vessels

Two other potential causes of shipping damage to pipelines are:

- Foundering, which involves a vessel sinking exactly on top of the pipeline, or
- Grounding where a vessel drifts to the shore due to mechanical failure and impacts the pipeline occurs.

The rate of geometric interference (ship footprint on pipeline trench) from ship sinking is less than 10^{-6} per year. As no shipping damage to the oil export pipeline has been brought forward, the best estimated wreck damage frequency 9.75×10^{-9} per km-yr from PARLOC database is taken for further calculation.

3.2.5 Corrosion

An elaborate study has been done in the "Oil Field Facilities Corrosion, Materials and Inspection Report".

Relevant conditions used in the Hydrocor predictions for the export pipeline by SGS (2006) are as follows:

- Inlet temperature 120°F
- CO_2 0.005 Mole % (based on saturation at 1 bar surge separator pressure)
- Water content 0.5 % volume
- Organic Acids 1967 ppm
- Bicarbonates 2006 – 3500 ppm
- Flowrate 70,000 bpd

Many oil export pipelines often see little or no corrosion, but there are cases where export oil pipelines do suffer from internal corrosion problems that are mitigated by pigging and chemical inhibition programs. There are many factors that influence the probability of corrosion in an oil pipeline:

1. Amounts of CO_2 in the gas phase (most of the GOM fields are considerably lower than the 1%)
2. Organic acid and bicarbonate concentrations
3. Fluid velocity that may maintain water in suspension (non-corrosive situation)
4. Fluid temperature (corrosion rate increases with rising temperature)
5. Presence of bacteria in the production system and effectiveness of mitigation
6. Low water-cut and protection by oil phase as water is entrained in the oil
7. Natural inhibitors in oil
8. Precipitation of paraffin or asphaltenes that protects the pipeline (GOM)
9. Formation of corrosion product layers or other scale layers

The effects of items 6~9 are all difficult to quantify, so we cannot take full credit for these un-quantifiable phenomena. However, by managing the risk, there will be plenty of opportunity to manage any potential corrosion issues for the export pipeline.

We expect that there will be some carryover of corrosion inhibitor from the production system that will have some beneficial effect on the export pipeline, but it is very difficult to predict the amount of protection.

At a level of 1900 ppm bicarbonate and with corrosion inhibitor availability in the export pipeline of 99.4%, the predicted actual corrosion rate is 0.15 mm/yr (6.1mpy). Over a 20-year period, this results in 3 mm corrosion loss. Allowing for the fact that there will be 5 years where the water content and/or velocity in the export pipeline will result in basically no corrosion and the combination of the conservative bicarbonate level and non-specific, but real benefit of oil wetting and pigging, we recommend a 3mm corrosion allowance be used.

In addition to water removal and corrosion inhibition, internal corrosion in the export pipeline will be managed with an appropriate cleaning pigging program and corrosion monitoring.

The monitoring strategy for the export line would involve operating the CI at least as soon as any produced water is evident in the system, but preferably from the first time oil is introduced into the system to assure that the export line is protected. Surveillance of the corrosion monitoring equipment will determine if adjustments in the CI injection volume can be made, or if it can be turned off all together, which would be very possible once the system is up to full and steady production over 110,000 BPD.

From the description above, we can come to the conclusion that the internal corrosion level of the pipeline can be very low; it is reasonable to take the best estimated internal corrosion failure frequency 4.91×10^{-7} per km-yr.

What's more, the Oil Export Pipeline is 50mm concrete coated and there is external anti-corrosion coating and cathodic protection all alone the pipeline, together with the low risk of external interference – results in that the best estimated failure frequency 1.84×10^{-7} per km-yr from PARLOC is employed in this report.

Thus we get the oil export pipeline failure rate of 6.75×10^{-7} per km-yr for corrosion on considering of both internal and external corrosion effects. These corrosion failure frequencies above are largely empirically judgment, incorporating comments from workshop with many experts' attendance.

3.2.6 Conclusion & Summary of Modification Results

The summaries of failure rates' modification results from detail analysis above are listed in Table 3.

The total pipeline failure frequency for the whole length (200.614km) of the pipeline is found to be less than $1.72x10^{-4}$ per-yr. This failure frequency is shown to be low and comparable to industry standard.

Cause	Failure Frequency (per km-yr)		
	Mid Portion	Near Marine Park	Near Shore
Trawl	0	0	0
Anchor	4.79E-08	4.79E-08	0.00E+00
Wreck	9.75E-09	9.75E-09	9.75E-09
Corrosion	6.75E-07	6.75E-07	6.75E-07
Material Defects	1.23E-07	1.23E-07	1.23E-07
TOTAL	8.56E-07	8.56E-07	8.08E-07

Table 3: Modification results of failure frequencies by causes (per km-yr)

3.3 Oil Spill With and Without LDS

3.3.1 Oil Spill Model

An oil spill model POSVCM from MMS has been employed to simulate the oil export pipeline leakages at various situations.

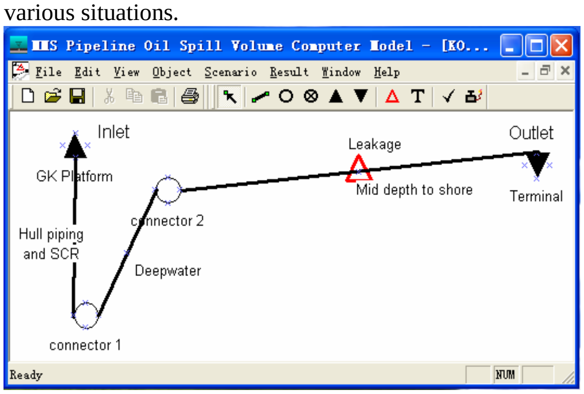

Figure 1: The Oil Export Pipeline Model.

The Pipeline Oil Spill Volume Computer Model (POSVCM) provides a methodology to determine worst-case discharges from seafloor pipelines. Inputs to POSVCM are parameters describing the configuration and characteristics of a pipeline system, the fluid it contains, and the leak or break from which the discharge occurs. Key outputs are the evolution of the release rate over time, the total mass of oil released, and a measure or the mean thickness of any eventual surface slick being formed. The system is composed of a Release Module and a Nearfield Module, linked together with necessary databases through a Graphical User Interface (GUI).

The Oil Export Pipeline has been soundly modeled in the POSVCM as illustrated in Figure 1. The entire oil export pipeline has been divided into five sections according to Table 1, and the mean internal diameter 0.4211m has been used to simplify the model.

3.3.2 Emergency Response

Discounting leaking size and pressure, the two components of a release volume from the oil pipeline are (a) the continued pumping that occurs before the line can be shut down and (b) the liquid that drains from the pipe after the line has been shut down.

A timely detection and affirmation of a leak will initiate a quick pipeline shut down response. The leak detection philosophy on the oil pipeline is divided into three-tiered approaches. The first tier approach involves the gross flow measurement, which will monitor the input volumes at the host and compare those with volumes received at the Oil and Gas Terminal (OGT). The second tier is the use of visual surveillance survey – either through routine vessels visual observation or even the routine air visual survey through helicopter flying the pipeline route. Finally, if required – as the third tier, the use of computational leak detection system with advanced flow modeling and/or statistical algorithm to determine the rate of mass balance changes and potential leak.

Leak detection performance is usually defined in terms of detecting a particular leak flow rate within a specified minimum period of time. The first tier approach may only be able to capture medium to large leak sizes. For smaller leak, without the use of computation al leak detection system, the operator will then have to rely on the second tier approach which is the routine visual survey. Depending on the routine nature/schedule of the visual observation, the leak detection could vary significantly from hours to days. For computational leak detection system, the detection time can vary from minutes to hours depending on leak sizes, transient operations and flow rate. Although the leak detection may need to be confirmed with visual, the total response time (with computational leak detection system) should be reduced significantly in particular – with regards to smaller leak sizes (from potentially days to hours).

The normal emergency response sequence to a leakage should be like this:

- Step 1: Leak is detected (LD) - leak continues;
- Step 2: Deployment of surveillance (DoS) to ascertain the detected leak signal- leak continues;
- Step 3: Leak confirmation- leak continues;
- Step 4: Pump shut-down and inlet valve shut-in to isolate the leak, the outlet valve at OGT to be left open to help reducing the pressure in the pipeline after confirming the leak- leak continues;
- Step 5: Mechanical recovery using booms/nets and skimmers will be deployed to site immediately, e.g. Split Mechanical Pipeline Repair Clamps are designed to encapsulate leaking or damaged pipe sections in a fast and effective means.

Assumptions of emergency response times before pipeline shut-in with LDS and Without LDS (herein, it means without LDS third tier as the description above) have been made based on comments of a conference with several experts' attendance. Thus, only the leaking process before shut-in is able to be modeled to figure out the oil spill volume, which is the main part of spilling.

3.3.3 Modeling Results

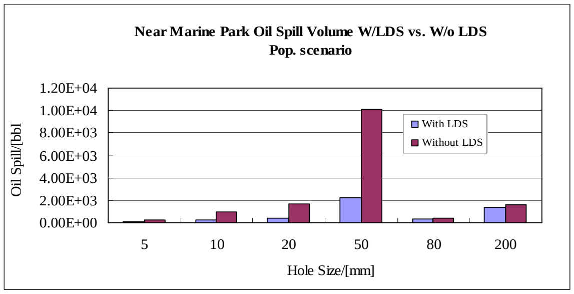

Figure 2: Operating Pressure Scenario Oil Leakage near Marine Park

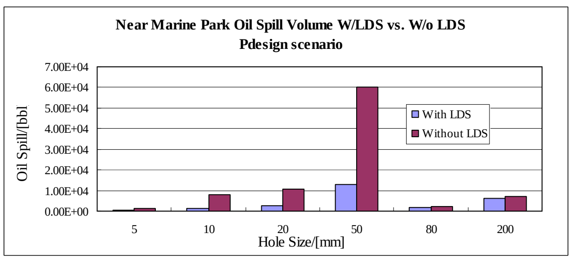

Figure 3: Design Pressure Scenario Oil Leakage near Marine Park

Based on the entire precondition above, three representative leaking hole sizes have been modeled by POSVCM at two different scenario: operating pressure scenario (from 121bar at host to 7bar at the OGT) and design pressure scenario (from 241bar at host to 90bar at the OGT).

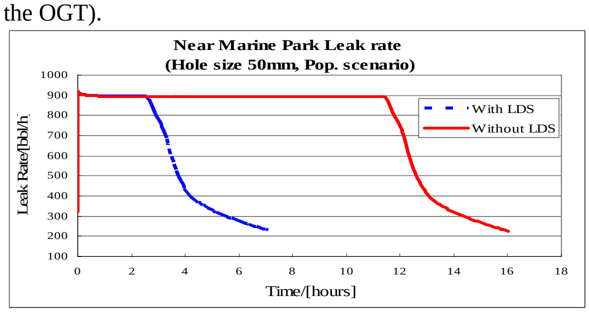

Figure 4: Operating Pressure Scenario near Marine Park Leak Rate at the Hole Size 50mm

Two typical figures (Figure 2 and 3) of oil spill with/without LDS in two different scenarios have show the decreasing of oil leakage from upstream to downstream, which is mainly because of pressure consumption along the pipeline. Further more, there are two samples of leak rates' variation against time at the hole size of 50mm given below to illustrate the differences of oil spill with/without LDS.

The oil spill models run from the very beginning of the leak and the leak rate tend to be constant if the leak rate is less than 100% of flow rate 150000bbl/d or 6250bbl/h before the pipeline shut-in. However, the leak rate will decline sharply once the inlet valve of the pipeline is shut in to mitigate the leakage.

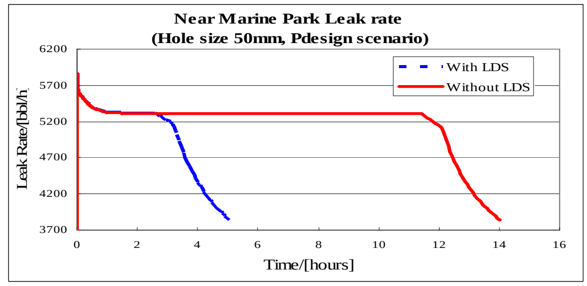

Figure 5: Design Pressure Scenario near Marine Park Leak Rate at the Hole Size 50mm

The oil spill calculation results illustrated above from Figure 2 to Figure 5 have revealed that the installation of statistical LDS can large reduce the time of leak detection, thereby mitigating the consequence of leakage.

3.4 Oil Dispersion Assessment

Two sensitive areas will be considered for oil dispersion assessment: 1) Near Shore K. Bay and 2) Near Marine Park.

The nearest section of pipeline to Marine Park is located between KP 168 and KP 171, for approx. 2000m. At this location, as with the remaining section of the shallow water section, the pipeline will be coated with 50 mm of concrete coating as additional mechanical protection.

An environmental impact assessment for the Oil Export Pipeline have been conducted and accepted by Department of Environmental on the 21st of July 2008.

The Near Marine park leak scenarios have been modeled in an EIA report for the oil export pipeline to the OGT. The results of the oil spill modeling study conducted to assess the extension and potential impact of oil to nearby shorelines have also been performed in the EIA report (ASA 2006).

This study further models the oil spill dispersion based on the potential leak sizes in the pipeline at various location near the marine park and near shore on the worst-case scenarios of both the NE and SW monsoon seasons. During the NE monsoon season, the model predicts a maximum of 90% to 100% probability of shoreline oiling southeast of the release site, due to the close distance of the release location to the shoreline. During the SW monsoon season, the model predicts a maximum of 60% to 70% probability of shoreline oiling, which would decrease with increasing distance of release from the shoreline.

During the oil spill dispersion, the dispersion can be divided into three parts: evaporation, diffusion and impact to Marine Park or Shore area. And a coarse assumption has been made takes into account the effects of wind and current see Table 4.

Leak sites	Vapor	Diffused in water	Affecting Shoreline
Near Marine Park	20%	40%	40%
Near Shore	25%	35%	40%

Table 4: Oil spill dispersion

Combined with the oil spill volume modeling results in last section of this report, the simulated oil quantity that may affect the Marine Park and Shoreline is listed in the following: Table 5 and Table 6

With LDS				
Leak size	Oil spill volume	Evaporation	Diffusion	Marine Park Impact
mm	bbl	bbl	bbl	bbl
5	57.21	11.44	22.88	22.88
10	228.69	45.74	91.48	91.48
20	358.50	71.70	143.40	143.40
50	2196.31	439.26	878.53	878.53
80	294.34	58.87	117.73	117.73
200	1312.13	262.43	524.85	524.85
Without LDS				
5	236.99	47.40	94.80	94.80
10	950.98	190.20	380.39	380.39
20	1652.90	330.58	661.16	661.16
50	10113.6	2022.72	4045.44	4045.4
80	375.11	75.02	150.04	150.04
200	1607.61	321.52	643.04	643.04

Table 5: Operating pressure scenario Marine Park affected oil quantity

With LDS				
Leak size	Oil spill volume	Evaporation	Diffusion	Shoreline Impact
mm	bbl	bbl	bbl	bbl
5	14.04	3.51	4.91	5.62
10	56.00	14.00	19.60	22.40
20	93.59	23.40	32.76	37.44
50	577.38	144.35	202.08	230.95
80	87.20	21.80	30.52	34.88
200	453.07	113.27	158.58	181.23
Without LDS				
5	52.23	13.06	18.28	20.89
10	209.06	52.27	73.17	83.63
20	344.16	86.04	120.46	137.67
50	2120.84	530.21	742.29	848.34
80	110.19	27.55	38.57	44.08
200	569.83	142.46	199.44	227.93

Table 6: Operating pressure scenario Shoreline affected oil quantity

Extensive discussion on how the oil spill may impact the marine and coastal environment can be found in EIA. Based on the results in the tables, there are several conclusions that can be drawn:

- Any oil spill may have significant impact for the environment at both near shore and Marine Park.
- LDS will provide greater benefits for small to medium size leaks.
- For large leaks, LDS will provide limited value as the response time will be similar for both with or without LDS.

At the marine park or near shore, the LDS will provide limited value due to rapid dispersion especially during monsoon session.

4 Leak Detection Criteria (LDC)

In this Section, we shall determine the minimum system requirements to enhance existing system to meet minimum detection requirements including a feasibility assessment of the CPM leak detection system – within ALARP principle.

The performance criteria are specified in terms of sensitivity, accuracy, reliability, and robustness. A balanced consideration of the criteria is required. For instance, focus on attaining ideal performance in one area, say sensitivity, may result in degradation of the other criteria. Most leak detection technologies attempt to attain a satisfactory tradeoff between sensitivity, accuracy, reliability, and the robustness by understanding the specific operating conditions of a pipeline and the operator's expectation.

DEP 31.40.60.11 identified that should the requirement of the LDS is the outcome of a Quantitative Risk Assessment (QRA), the accuracy and sensitivity generally should be treated as the essential performance criteria to limit the environmental consequences.

QRA results reveal that the impact for the Marine Park and Shoreline without LDS is much severer than with LDS and the result is unacceptable, so it is significant for us to establish a system to assist the Emergency Response Team (ERT) to quickly identify, locate and employ a mitigation measure to contain the damage should a leak incident occurs. It is recommended that an appropriate LDS is to be provided to reduce the impact of the oil spill consequences.

The performance criteria for the LDS need to be established according to the API 1130 recommendation. A detail discussion and recommended acceptance limit for each of the performance criteria for the selection of LDS is provided in the following section.

4.1 Sensitivity

Defined as a composite measure of the size of leak that a system is capable of detecting, and the time required for the system to issue an alarm in the event that a leak of that size should occur (API 1995b). The relationship between leak size and the response time is dependent upon the nature of the leak detection system. Some leak detection systems manifest a strong correlation between leak size and response time, while with others, response time is largely independent of leak size. Note that there are no known systems that tend to detect small leaks more quickly than large leaks. Leak detection performance is usually defined in terms of detecting a particular leak flow rate within a specified minimum period of time.

Typical limit is that leaks about 0.5% of flow for liquid or greater, detectable within 1 to 60 minutes.

In terms of response time, the regulations do not stipulate a time frame in which the system is capable of detecting leaks. Where available, field performance data are presented in the evaluation, but it is the pipeline operating company's responsibility to establish an appropriate response time for their pipelines. Reliability

4.2 Reliability

Reliability is defined as a measure of the ability of a leak detection system to make accurate decision about the possible existence of a leak in the pipeline. Accurate leak detection directly related to the probability of detecting a leak, given a leak does in fact exist, and the probability of incorrectly declaring a leak, given that no leak has occurred. A system that incorrectly declares leaks is considered to be less reliable.

Reliability pertains only to the functionality of the statistical leak detection software without regards to the data acquisition system performance, availability of pipeline instrumentation and communication equipment, or any other factor beyond the control of the system vendor.

Feed back provided within SHELL operation group indicated that the installed LDS on the existing pipeline could be tuned to eliminate the false alarm significantly. This is also supported by information from vendors that the recent technology of pattern recognition is utilized to enable to LDS to eliminate the false alarm without notable effect on the sensitivity.

"Zero" false alarms should be the objective, but must be balanced by maintaining reasonable model sensitivity.

4.3 Robustness

Robustness is defined as a measure of the system capability to continue to function and provide useful information even under changing pipeline conditions of operation, or in condition where data is lost or suspect. A system is considered to be robust if it continues to function under less than ideal conditions.

The Model should be able to perform under a variety of conditions, including slack-line flow and true multiphase flow application.

4.4 Accuracy

Accuracy is a measure of leak detection system performance related to estimation parameters such as leak rate, total volume lost, and leak location (API, 1995b). A system, which estimates these parameters within an acceptable degree of tolerance, as defined by the pipeline operator, is considered to be accurate. Often times a leak detection system will use existing pipeline instrumentation such as volumetric gauges and floats in their processes. The accuracy of these leak detection systems is largely dependent upon the accuracy of the instrumentation.

For this project, leak location accuracy is discussed in terms of the capability of a technology to locate the leak within so many feet of an indicating sensor.

Some system can provide estimates of leak flow rate or total volume and mass lost and leak location. Different technique can provide different estimates with varying accuracy. The accuracy of a leak detection technology in estimating measurement parameters such as leak rate and total volume lost is evaluated in terms of the accuracy, repeatability, and precision of the recommended pipeline instruments themselves.

Typical leak rates and total volume lost should be within 10% and the location accuracy is typically within 5 to 10% of the distance between the nearest instruments bounding the "leak section".

Performance Metric	Specific Performance Criteria	Steady State	Transient State
Sensitivity	Minimum detectable leak rate	0.50%	2.00%
	Response time for 100% leak	4 min	2 min
	Response time for 50% leak	4 min	2 min
	Response time for 10% leak	7 min	8 min
	Response time for 5% leak	16 min	27 min
	Response time for 1% leak	80 min	400min
Reliability	Incorrect leak alarm declarations rate overall	1 time / annum	2 times /annum
Robustness	loss of function due to pressure outages	NO	NO
	loss of function due to temperature outages	NO	NO
	loss of function due to flow outages	YES	YES
	loss of function due to pump state change.	NO	NO
	loss of function due to valve state change.	NO	NO
	Start up stabilization period	NO	NO
Accuracy	Leak location for 100% leak	6%	6%
	Leak location for 15% leak	7%	8%
	Leak location for 2% leak	21%	17%
	Leak location for 1% leak	27%	30%
	Leak rate error	1%	50%

Table 7: LDS Performance Indicator Criteria according to API 1130

4.5 Leak Detection Performance Criteria

Selecting of the LDS is the responsibility of the operating company to be weigh based on the which performance criteria is to be prioritized coupled with the available Emergency Response Plan. The performance criteria for the LDS need to be established according to the API 1130 recommendation and the recommended acceptance limit for each of the performance criteria of the LDS is listed in Table 7. The limit is compiled from on the information provided by various LDS vendors.

5 Conclusions & Recommendations

5.1 QRA Study Results

There are various risk contributors to certain sections of the Oil Export Pipeline. The Oil Export Pipeline anglicized here is very long, about 200.614km. A large part of the pipeline is located in mid to shallow water with the last third of the pipeline passing through sensitive coastal areas and close to the Marine Park. In this report, risks of three representative site leaks have been addressed: Mid Portion at KP 100, Near Marine Park at KP 170 and Near Shore at KP 198.

Table 3 has shown different causes of failure frequencies at the three representative leak sites. And the total pipeline failure frequency for the whole length (200.614km) of the pipeline is found to be 1.72 x 10^{-4} per annum. This failure frequency is shown to be low and comparable to industry standard. From the QRA, it can also be concluded that there are little, if any, opportunities for further reduction to the failure frequency.

The benefit of LDS has been shown in the figures of oil spill modeling results, which have indicate that the installation of LDS can largely reduce the oil spill volume. Thus, suitable LDS is recommended to be installed to reduce the impact of oil spill consequences.

The oil spill dispersions calculation has been performed to estimate the amounts that will affect the marine park or shore area. The results thus indicate as follows:

1. For leak within 10 km of Marine Park or shore approach, regardless of leak sizes, the leak may affect significant part of Marine Park or shore approach – dependent on the prevailing sea and wind condition.
2. For leak further away from Marine Park or Shore Approach, smaller leak sizes, the use of computational leak detection system will help in the following:
   a) Positively identify that the oil spill belongs to the Oil Export Pipeline (considering that there are other pipelines within the vicinity)
   b) Reduce the response time to both detect and locate the leak – and thus, may significantly reduce the potential impact of the spill to the sensitive areas.

From the above results, the following conclusions can be reached:

1. The pipeline design and integrity management system is assessed to be sufficiently comprehensive resulting in low failure frequency per annum and little, if any, opportunities to further reduce this failure frequency.
2. Near the marine park area or within the vicinity of K. Bay, the likelihood of failure is very low as the operating pressure is very low – resulting in high "pseudo" corrosion allowance and higher "pseudo" mechanical resistance.
3. Overall assessment of the failure frequencies indicated that the major contributing factor for failure is the internal corrosion – most likely yielding to very small leak to medium size leaks.
4. Computational leak detection system will not provide any benefits for large leak or very small leak (less than 1% flow rate – for single phase system).
5. For medium and small leak at close proximity to Marine Park or near the shore approach – the computational leak detection system will not help in reducing the spill impact. The computational LDS in this case will help in positive identification on the leaked pipeline and acts as back up to the PI for the pipeline isolation valves and facilities status.
6. Computational LDS will be of most benefit to medium and small leak of medium distance to the Marine Park/shore approach – whereby LDS will bring the following benefits:
   a) Improved response time (detection time and leak location time) – in particular during transient runs such as pigging.
   b) Positive identification of the pipeline that leaked – especially considering the other pipelines on the K. Bay/Marine Park area (7 pipelines in total, of which 4 pipelines are liquid lines).
   c) Confidence to continue operation if no leak is detected in the system but there is a reported spill in the vicinity of K. Bay/Marine Park area (potentially due to spill from other facilities/pipelines/vessels, etc).
7. The study also concludes that there are other benefits of computational LDS, as follows:
   a) Act as potential back up to PI system for the pipeline isolation valves and facilities status
   b) Tracking system for the allocation flow meter drift

The recommendations from the QRA study are thus, as follows:

1. In the unlikely event that a leak occurs, detection through conventional leak detection such as conventional pressure/flow monitoring and/or visual survey (helicopters/boats) may not be sufficient for detection of small to medium leak sizes (i.e., 8 – 80 mm) and/or may result in extended leak detection/leak location response time. These undetected leaks are within the range of leak sizes that computational leak detection can be of benefit. These undetected leaks – within the vicinity or proximity of the Marine Park/Shore approach may result in major consequences. For these types of leaks – the use of computational leak detection to reduce the impact of the spill is recommended.
2. For the unlikely event that leak occurs at immediate vicinity to the Shore approach area or immediately near the Marine Park, immediate response in the mitigation of spill should be the strategy to reduce the consequences of the spill.

3. In order to reduce the likelihood of damage from mechanical impact especially at the K. Bay area, ban on trawling on the K. bay should be considered. This ban will also be beneficial to the proliferation of fish habitats and soft bottom corals around the K. Bay/Marine Park area.

5.2 General LDS Instrumentation Requirement

This section contains a description of instrumentation required to support the leak detection system including the required performance specifications. The choice of instrumentation is client-driven because cost would be a major consideration in the selection process. The recommended acceptance limit for each of the performance criteria of the LDS has been listed in Table 7 above. The limit is compiled from on the information provided by various LDS vendors.

5.3.1 Flow Measurements

Flow measurements at the boundaries of each pipeline segment (both inlet and outlet) are important as a limiting factor for the LDS sensitivity.

5.3.2 Pressure and Temperature Measurements

In additional to flow rate data, leak detection systems rely on the availability of pressure and temperature sensors on the pipeline configuration. Typically a pressure and temperature reading would be important for all inlet and outlet points.

5.3.3 Instrumentation Quality

It is necessary for us to define the quality of the instruments to enable the LDS to function with expected performance. The instrument quality is described by accuracy, repeatability and update rate as shown in the Table 8, the instrument quality below is compiled from the input provided by various LDS vendors.

5.3.4 LDS Computer Hardware Minimum Specification

LDS of Pipeline can be implemented as:

- One stand-alone PC to be located at Offshore Platform or the OGT as minimum
- Two PCs running parallel at both Offshore Platform and the OGT

Option B will provide LDS redundancy and dedicated for the OGT operators with minimum cost impact. The following minimum specifications for the PC shall be provided: Dual Core Processor, 2900 MHz, 2000 MB RAM, 500 GB hard disk, CD-RW/DVD Drive, Dual Network Card and Modem, LCD Monitor, Keyboard and Mouse, Windows XP Professional 32 Bit Operating System.

Instrument	Accuracy required	Repeatability required	Update Rate required
Flow	0.50%	0.15%	5 sec
Pressure	0.20%	0.10%	5 sec
Temperature	0.15%	0.05%	5 sec

Table 8: Instrument Quality

5.3.5 Communication

The communication protocol between LDS PC to gather the flow, pressure and temperature data from DCS are either via OPC, DDE, ODBC or Modbus.

Ethernet cable connection or serial cable connection could be the physical connection between LDS PC and DCS at the Offshore Platform/OGT.

Final selection of data communication method is to be determined with respective DCS Vendor. DCS Vendor at Offshore Platform has to ensure data communication with DCS Vendor at the OGT within specified time.

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