IMPACT OF INTERNAL INSPECTION DATA UNCERTAINTIES ON RISK ANALYSIS FOR DESIGN LIFE EXTENSION OF SUBSEA PIPELINE – A CASE STUDY

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Many existing subsea pipelines are approaching or have exceeded their original design life. Pipelines are designed for a specific life span, depending on the reservoir capacity, as well as on process parameters and substances that should be conveyed. Nevertheless, many fields have a reservoir capacity larger than the predicted one. In this case, oil companies check if it is possible to extend the design life of the pipeline, i.e. if the status of the pipeline is capable to withstand the maximum allowable operating conditions foreseen during this additional period. The internal inspection performed by means of intelligent pig, when feasible, is the most efficient solution in order to highlight the real status of the defects of a subsea pipeline. The intelligent pig is a vehicle capable to run through the pipe and to gather positions and dimensions of the pipeline defects. In order to extend the design life of the subsea pipelines, risk analyses are carried out to define the risk level, until the line is in operation. The risk level is a combination of frequencies and consequences of the identified accidental scenarios, following a possible release. Frequencies are evaluated considering all potential causes that can lead to loss of containment scenarios. In particular, release frequencies due to corrosion are calculated considering the probabilities that material defects result in failure scenarios. These probabilities depend on the inspection data and are affected by the data uncertainties. A probabilistic assessment is performed considering the uncertain data collected by the internal inspection. The calculated risk level changes according to the data uncertainties: if the measurements of the inspection vehicle are not so much accurate, an intolerable risk level can be found even when the pipeline defects are not so critical.

This paper reports the approach used for an actual case study: a subsea pipeline with a twenty-five years design life, carrying multi-phase oil with sour gas (i.e. with H2S). The paper focuses on the impact of the detection accuracy during the pipeline internal inspection on the calculated risk level, as well as on the risk reduction measures to be adopted in practice.

I. INTRODUCTION

During this recent economic stagnation, the Oil & Gas projects are suffering the decline of profits and the increase of costs. In this context, Companies are increasingly focusing in the design life extension projects, aimed to operate plants also when their life span is exceeded. In order to extend the design life of a pipeline, some activities should be developed aimed at demonstrating that plants are capable to still produce without jeopardize the human health, the environment and the neighboring assets. In particular, the design life of pipelines is determined by considering the foreseen reservoir capacity, process parameters and substances that should be conveyed via this facility. Nevertheless, it can occur that reservoir capacity is larger than the predicted one. In this case the Companies verify whether it is possible to extend the design life of the pipelines in order not to interrupt their production. For highlighting the real status of pipelines, Companies implement monitoring activities. The final goal of this inspections is to evaluate if the status of pipeline is capable or not to withstand the maximum allowable operating conditions foreseen for the additional period. The internal inspection by intelligent pig is the most efficient solution in order to record the material defects of pipelines. Usually, the internal inspection is performed by means of an appropriate vehicle capable to run through the pipe and to register the positions and the dimensions of the pipeline defects. Then Companies have to process all the gathered data and to calculate the probability that these defects can lead to loss of containment scenarios. Release frequency evaluation and consequences analyses will be performed. By the combination of frequencies and consequences, the reached risk level will be assessed and compared to Company risk acceptance criteria. If more than one internal inspections are conducted at different time intervals, the expected corrosion rate can be evaluated and the risk level reached at the end of the desired period can be predicted.

II. CASE STUDY

The case study presented in this paper refers to a subsea pipeline life extension project. The pipeline connects a platform with an onshore refinery, it is composed by a riser and a subsea pipeline. The subsea pipeline was commissioned in the past with a design life of 25 years. The pipeline starts from the platform, where the extracted oil is collected, and reaches the onshore refinery, running for approximately 12 kilometres and reaching a maximum depth of 65 m. It is made up of API 5L X52 and it is designed for a Maximum Allowable Operating Pressure (MAOP) of 80 bar. The nominal diameter is 12 inches and the nominal thickness is 11.13 mm. It is coated with 2 mm of internal anti-corrosion coating and with 50 mm of external concrete coating. The pipeline characteristics are summarized in the TABLE I.

TABLE I. Pipeline Design Data

Description	Value
Year of Construction	1991
Design life (years)	25
Design life ending	2016
Pipeline length (km)	12.1
Pipeline diameter (inch)	12
Thickness (mm)	11.13
Steel type	API 5L X52
Maximum depth (m)	65
MAOP (bar)	80
Anti-corrosion coating (mm)	2
Concrete coating (mm)	50

The pipeline carried oil with a significant amount of impurities (i.e. water, contaminants and sour gas). During the 2012, it was decided to undertake an internal and external inspection aimed to gather information on the pipeline integrity. Three years later (i.e. 2015), when the pipeline was approaching his original design life, another internal and external inspection was undertook to highlight the progress of the material defects identified during the previous inspection. This second inspection allowed Company to evaluate the actual corrosion rate, to estimate the current risk level and to forecast the pipeline status in the next years. The goal of the design life extension project was to extend the pipeline life span of other 7 years. In order to continue to operate this pipeline, Company has to produce the documentation to demonstrate that the pipeline life extension will not lead to health and safety issues related to people, to environment pollution and assets damage characterized by too high risk levels. To prepare this documentation, the following activities should be performed:

- Statistical analysis of data gathered by the inspection vehicle;
- Evaluation of the internal and external corrosion rates related to the progress of internal and external defects (based on inspections data);
- Assessment of the probabilities that defects can lead to loss of containment;
- Calculation of pipeline release frequencies;
- Analysis of possible consequences of the accidental release;
- Definition of the overall risk level, combining scenario frequencies and consequences, related to people, environment and asset.

II.A. Statistical Analysis of Internal Inspection Data Set

An inspection vehicle, capable to run through the pipe, was used in order to gather information regarding pipeline material defects. Each identified material defect was characterized by depth, length, width, position and orientation along the pipeline. The new generation intelligent pig is capable to give information regarding the internal and external defects by exploiting a magnetic pulses technique: a metal loss defect tends to disturb the magnetic field, causing the flux to leave or leak from the pipe wall (Ref. 1). It is to note that each defect characteristic (i.e. depth, length, width, position and orientation) is strongly dependent on the inspection vehicle accuracy. The inspection accuracy can be considered the main contributor to the uncertainties of the gathered data. In TABLE II the worst defects data revealed during the pipeline internal inspection, in terms of position, type, depth, length, width and orientation with their accuracy, are shown.

TABLE II. Worst Defects Characterization results from inspection vehicle - 2015

#	Position			Type	Depth/Pipeline Nominal Thickness		Length		Width		Orientation	
	Welding	X (m)	± x (m)	Int/ Ext	δ/t (%)	± d/t (%)	L (mm)	± l (mm)	W (mm)	± w (mm)	O (hr:min)	± o (hr:min)
1	a	0.6	± 0.1	Ext	31	15	169	20	43	25	01:45	00:10
2	b	5.9	± 0.1	Int	24	15	126	20	29	25	05:45	00:10
3	c	8.6	± 0.1	Int	26	15	231	20	123	25	06:00	00:10
4	d	0.1	± 0.1	Int	20	15	256	20	31	25	06:00	00:10
5	e	8.4	± 0.1	Ext	25	15	138	20	69	25	11:00	00:10
6	f	9.0	± 0.1	Ext	35	15	100	20	70	25	06:00	00:10
7	g	2.2	± 0.1	Ext	26	15	113	20	92	25	11:15	00:10

The position (X) shown in table is the relative distance from a specific welding (a, b, c, d, e, f, g), in this way different inspection results can be compared more easily. The defect #1 is located on the riser, all the others on the subsea pipeline. All defects which have dimensions higher than the detection accuracy have to be analysed. It is advisable to consider separately internal and external material defects due to different corrosion processes. When the collected defects data are a significant number the statistical approach will give reliable results. In this case, the approach was based on a Weibull distribution that best represented the trend (Refs. 2 and 3). The statistical approach is to be taken into account also when two subsequent inspections cannot be aligned due to a poor accuracy of measures: in these cases it is not possible to match the same defect on the two inspections data sets. In the following TABLE III and TABLE IV statistical results calculated for the inspections performed respectively on 2012 and 2015 are reported.

TABLE III. Statistical Results of Internal and External Defects – 2012

Defect Type	Defect depth/Pipeline Nominal Thickness (%)			Defect Length (mm)			Defect Width (mm)		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
Internal	1.0	14.2	33.0	6.0	25.5	297.0	12.0	27.2	404.0
External	1.0	16.9	25.0	10.0	59.9	181.0	16.0	134.8	647.0

TABLE IV. Statistical Results of Internal and External Defects - 2015

Defect Type	Defect depth/Pipeline Nominal Thickness (%)			Defect Length (mm)			Defect Width (mm)		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
Internal	1.0	18.0	38.0	6.0	52.4	462.0	14.0	56.7	512.0
External	2.0	21.82	42.0	8.0	79.13	335.0	15.0	212.6	819.0

It is to be pointed out that to calculate the average values of defect characteristics, the measures lower than the detection accuracy have not been considered.

II.B. Defect Growth Rates Evaluation

Statistical results have been further utilized to obtain the defect growth rates, which will be used to forecast the defect progress in the next years and to evaluate pipeline risk level for the additional period. The growth rates evaluation is based on Eq. 1.

$$GR = \frac{\left(DMCV_{2015} - DMCV_{2012}\right)}{(2015 - 2012)}. \qquad (1)$$

Where:

GR Growth Rate in each defect directions (Depth, Length, Width)

DMCV Defect Mean Characteristic Value (Depth, Length, Width)

The growth rate in depth, length and width defect directions allows to evaluate the characteristic linear progress rate for the pipeline under study (Ref. 4). The results of this calculation for our case study is summarized in TABLE V.

TABLE V. Defect Growth Rate Results

Defect Type	**GR (mm/year)**		
	Depth	**Length**	**Width**
Internal	0.15	9.30	10.21
External	0.21	7.41	29.91

Basically, this analysis is useful only when predicted results are needed. Additionally, it is possible to obtain the defect growth rates results only if two consecutive internal inspections results are available for the pipeline under study.

II.C. Probability of Loss of Containment

The assessment of loss of containment probabilities represents the critical point of the analysis: the results of risk analysis is strongly dependent on the probabilities of release scenario from defects. The international standard DNV RP-F101 (Ref. 5) has been taken into account in order to calculate the loss of containment probability of each pipeline defect. Probabilistic assessments of pipes with metal loss defects can be based on the following limit state function (Ref. 5):

$$g = p(P_f) - p(P_{op}). \qquad (2)$$

Where:

p	Probability
g	Loss of Containment Probability
Pf	Failure Pressure related to each pipeline defect (see Eq.3)
Pop	Operating Pressure

$$P_f = h_m \cdot \frac{2 \cdot t \cdot SMTS}{(D-t)} \cdot \frac{1 - h_d \cdot \left[\left(\frac{j}{t} \right) + e_d \cdot s_{j/t} \right]}{1 - \frac{h_d \cdot \left[\left(\frac{j}{t} \right) + e_d \cdot s_{j/t} \right]}{Q}}. \qquad (3)$$

Where:

P_f	Failure Pressure related to pipeline defect
h_m	Partial safety factor for longitudinal corrosion model prediction
t	Nominal pipe wall thickness (mm)
SMTS	Ultimate tensile strength (N/mm^2).
D	Pipeline Outside Diameter (mm)
h_d	Partial safety factor for corrosion depth
(j/t)	Defect depth detected by the inspection vehicle
e_d	Factor for defining a fractile value for the corrosion depth
$s_{j/t}$	Standard deviation considering depth accuracy
Q	Length correction factor (see Eq.4)

The length correction factor (Q) depends on defect length (L), nominal thickness (t) and pipeline outside diameter (D):

$$Q = \sqrt{1 + 0.31 \cdot \left(\frac{L}{\sqrt{D \cdot t}} \right)^2}. \qquad (4)$$

Based on the Eq.2, a Monte Carlo simulation analysis was performed. Defect dimensions and maximum operating pressure are considered random variables to account for the associated uncertainty (Ref. 1). On the other hand, corrosion growth rates, material yield stress, pipeline diameter and thickness have been considered fixed (Ref. 5). Adjacent defects, that meet the requirements of DNV RP-F101 (Ref. 5) have been considered as interacting defects. Monte Carlo simulations have been performed for each identified defect. The main results, related to the defects listed in TABLE II, are shown in TABLE VI. In order to estimate the loss of containment probability on years after the 2015, depth and length of the identified defect on 2015 are increased according to its growth rates.

TABLE VI. Loss of Containment Probability

#	Loss of Containment Probability							
	2015	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
1	3.98E-04	7.56E-04	1.46E-03	2.30E-03	4.30E-03	6.41E-03	1.05E-02	1.66E-02
2	1.37E-05	2.91E-05	5.88E-05	1.19E-04	2.21E-04	3.78E-04	7.31E-04	1.14E-03
3	3.23E-04	4.81E-04	8.32E-04	1.22E-03	1.84E-03	2.48E-03	3.91E-03	5.60E-03
4	8.77E-05	1.41E-04	2.33E-04	3.51E-04	5.40E-04	7.83E-04	1.23E-03	1.74E-03
5	2.80E-05	7.23E-05	1.41E-04	3.01E-04	5.81E-04	1.03E-03	1.93E-03	3.50E-03
6	1.19E-04	2.55E-04	5.73E-04	1.20E-03	2.42E-03	4.43E-03	7.65E-03	1.37E-02
7	1.37E-05	3.63E-05	7.82E-05	1.84E-04	4.07E-04	7.49E-04	1.54E-03	2.67E-03

II.D. Frequency Assessment

Once identified the loss of containment probabilities related to each pipeline defect, frequency assessment need to be performed with the aim of analyzing all causes of pipeline loss of containment scenario. Third party interaction frequencies and other causes frequencies to be added to the frequencies due to corrosion assessed from pipeline internal inspections have been taken from PARLOC Database (Ref. 6). Release hole size (1” or 4”) has been associated with each identified defect by analyzing its mean dimensions. Total release frequencies have been calculated for riser and pipeline. The results related to release frequencies from riser are reported in TABLE VII and TABLE VIII for 2015 and 2022, respectively.

TABLE VII. Riser Total Release Frequencies - 2015

Hole Size Release	Release Frequency due to Corrosion or Material Defect (occ/year)	Release Frequency due to Third Party Interaction (occ/year)	Release Frequency due to Other Cause (occ/year)	Total Release Frquency (occ/year)
1”	-	-	-	**<1.00E-10**
4”	4.01E-04	-	3.48E-05	**4.36E-04**

TABLE VIII. Riser Total Release Frequencies – Forecast 2022

Hole Size Release	Release Frequency due to Corrosion or Material Defect (occ/year)	Release Frequency due to Third Party Interaction (occ/year)	Release Frequency due to Other Cause (occ/year)	Total Release Frquency (occ/year)
1”	-	-	-	**<1.00E-10**
4”	2.05E-02	-	3.48E-05	**2.05E-02**

The results related to release frequencies from pipeline are reported in TABLE IX and TABLE X for 2015 and 2022, respectively.

TABLE IX. Pipeline Total Release Frequencies – 2015

Hole Size Release	Release Frequency due to Corrosion or Material Defect (occ/year)	Release Frequency due to Third Party Interaction (occ/year)	Release Frequency due to Other Cause (occ/year)	Total Release Frquency (occ/year)
1”	3.10E-06	-	-	**3.10E-06**
4”	6.13E-04	1.74E-06	3.01E-05	**6.45E-04**
FB	**-**	6.09E-06	1.01E-05	**1.61E-05**

TABLE X. Pipeline Total Release Frequencies – Forecast 2022

Hole Size Release	Release Frequency due to Corrosion or Material Defect (occ/year)	Release Frequency due to Third Party Interaction (occ/year)	Release Frequency due to Other Cause (occ/year)	Total Release Frquency (occ/year)
1”	-	-	-	**<1.00E-10**
4”	4.08E-02	1.74E-06	3.01E-05	**4.09E-02**
FB	**-**	6.09E-06	1.01E-05	**1.61E-05**

Event tree analyses were performed to obtain accidental scenario frequencies, by taking into account the ignition probabilities and the timing of ignition according to the IP-UKOOA Report (Ref. 7). In order to properly evaluate the onshore and offshore sections, release frequencies and accidental scenario frequencies have been splitted into two different contributes. The results related to accidental scenario frequencies are reported in TABLE XI and TABLE XII for 2015 and 2022, respectively.

TABLE XI. Accidental Scenario Frequencies – 2015

Event		Release Frequency [occ/year]	Accidental Scenario Frequency [occ/year]			
			Pool/Jet Fire	Explosion	Flash/Pool Fire	Dispersion
Subsea Pipeline	1”	3.10E-06	8.11E-09	-	2.80E-09	3.09E-06
	4”	3.91E-04	3.96E-06	-	1.37E-06	3.85E-04
	FB	1.61E-05	2.04E-07	-	7.03E-08	1.58E-05
Onshore Pipeline	4”	2.55E-04	6.44E-06	-	2.22E-06	2.46E-04
	FB	1.84E-07	7.49E-09	-	2.58E-09	1.74E-07
Riser	4” Submerged	3.66E-04	2.12E-05	-	7.32E-06	3.37E-04
	4” Emerged	6.97E-05	4.04E-06	-	1.39E-06	6.43E-05

TABLE XII. Accidental Scenario Frequencies – Forecast 2022

Event		Release Frequency [occ/year]	Accidental Scenario Frequency [occ/year]			
			Pool/Jet Fire	Explosion	Flash/Pool Fire	Dispersion
Subsea Pipeline	4”	1.39E-02	1.41E-04	-	4.87E-05	1.37E-02
	FB	1.61E-05	2.04E-07	-	7.03E-08	1.58E-05
Onshore Pipeline	4”	2.69E-02	6.81E-04	-	2.35E-04	2.60E-02
	FB	1.84E-07	7.49E-09	-	2.58E-09	1.74E-07
Riser	4” Submerged	1.72E-02	1.00E-03	-	3.45E-04	1.59E-02
	4” Emerged	3.28E-03	1.90E-04	-	6.57E-05	3.03E-03

In TABLE XI and TABLE XII, the scenario corresponding to the light grey boxes, were not further considered in the analysis because they were lower than the frequency credible threshold (i.e. 1.00E-07). Accidental scenario frequencies due to FB rupture are time independent because they are related only to third party interactions and other causes independent from the defects growth.

II.E. Consequences Evaluation

Consequences analyses have been simulated with the DNV Phast software (Ref. 8) in case of onshore release, and an in-house software for offshore release. Release flow rate and damage distances related to each accidental scenario have been calculated. TABLE XIII reports the main results.

TABLE XIII. Damage Distances

Event		Release Flow Rate [kg/s]	Damage Distances (*) [m]							
			Flash Fire		Jet Fire		Pool Fire		Toxic Dispersion	
			LFL	LFL/2	12.5 kW/m²	37.5 kW/m²	12.5 kW/m²	37.5 kW/m²	IDLH	LC50
Subsea Pipeline	1”	3.45	5	8	-	-	15	5	6	NR
	4”	109.8	12	22	-	-	19	6	18	3
	FB	1005	21	36	-	-	19	6	33	3
Onshore Pipeline	4”	31	12	23	15	4	22	NR	10	1
	FB	283	30	58	36	12	30	NR	36	3
Riser	4” Submerged	117	18	31	-	-	20	NR	28	4
	4” Emerged	114	17	42	36	30	20	NR	34	2

(*) Damage distances reported considering the worst case scenario (between 2F and 5D weather classes) at 2 meter height. NR = Not Reached

II.F. Risk Assessment

Risk assessment is the analysis required to obtain the certificate for the requalification of the pipeline. Final results of the risk assessment is the overall risk level which is based on the Company Risk Matrix (see TABLE XIV). Risk Ranking is performed for people, environment and asset by combining accidental scenario frequencies (please refer to chapter II.D) and consequences expressed as damage distances (please refer to chapter II.E).

TABLE XIV. Typical Company Risk Matrix

		Hazard Frequency					
		0 < 10^{-6}	**A** $10^{-6} – 10^{-4}$	**B** $10^{-4} – 10^{-3}$	**C** $10^{-3} – 10^{-1}$	**D** $10^{-1} – 1$	**E** > 1
Consequences Severity	**1** Negligible	01	A1	B1	C1	D1	E1
	2 Minor	02	A2	B2	C2	D2	E2
	3 Moderate	03	A3	B3	C3	D3	E3
	4 Severe	04	A4	B4	C4	D4	E4
	5 Major	05	A5	B5	C5	D5	E5

Three different colours classify the risk as:

- Continuous improvement (CI, green): the level of risk is broadly acceptable and only generic control measures are required aimed to avoiding deterioration;
- Risk reduction measure (RRM, yellow) or ALARP (As Low As Reasonable Practicable): the level of risk can be tolerable only once a structured review of risk-reduction measures has been carried out (for instance, by means of cost and benefit analysis);
- Intolerable Risk (IR, red): the level of risk is not acceptable; risk control measures are required to move the risk figure to the previous regions.

Hazard frequencies and Consequences severity are classified into different classes, 0 to E and 1 to 5 for frequencies and consequences respectively, where both increase progressively. Border values of each category depends on Company Risk Matrix. Consequences severity are evaluated considering the effects on people, environment and assets of the identified accidental scenarios. For instance, severity class 5 for people is considered when multiple fatalities can occur as a result of fire, explosion or toxic dispersion scenarios; severity class 4 for environment is taken into account when oil spillage amount is between 100 and 1000 m3 and the involved area is lower than 100 square miles; severity class 5 for asset is chosen when the production downtime is higher than three months or the repair cost is higher than 25 million dollars. The risk ranking performed for each identified potential hazard allow understanding if the foreseen risk reduction measures and further studies are sufficient to guarantee a low enough risk level or if any additional recommendation is required. The potential hazards were classified for people, environment and asset, taking into account the following risks: Risk for People at Platform (P1); Risk for People at Onshore Refinery (P2); Risk for People in Vessels crossing marine waters above the pipeline route (P3); Risk for Oil Dispersion in the Sea (E1); Risk for Oil Dispersion on the Ground (E2); Risk for Vessels crossing marine waters above the pipeline route (A1); Risk for Assets at Platform (A2); Risk for Assets at Onshore Refinery (A3). TABLE XV shows the results of risk ranking assessment.

TABLE XV. Risk Ranking Results

Target	**Scenario**	**Risk Ranking**							
		2015	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
People	P1								
	P2								
	P3								
Environment	E1								
	E2								
Asset	A1								
	A2								
	A3								
Overall Risk									

The risk level increases with time due to the increase with time of the scenario frequencies due to corrosion: since the material defects increase with time, their dimensions due to corrosion phenomena, release probabilities associated to these defects, scenario frequencies and associated risk level increase accordingly. The overall risk is ALARP until 2017, when it becomes Intolerable due to the oil dispersion in the sea and on the ground (i.e. E1 and E2). To continue to operate the pipeline, it was recommended to perform an internal inspection before the 2017 in order to evaluate the real state of the pipeline, recalculate the defects growth rate according to the current trend, and check if pipeline risk level is still acceptable.

II.G. Sensitivity Analysis

A sensitivity analysis has been performed varying the accuracy of the measurement reported in TABLE XVI. The base case considered in this paragraph is related to defect #1 reported in TABLE VI, i.e. depth/thickness ratio accuracy ±15% and length accuracy ±20 mm. The accuracy of the depth/thickness ratio has been modified in ±10% and 20% in order to understand the impact on defects release probabilities and then on risk analysis results. Also the accuracy for length measurement has been changed in ± 15 mm and ± 25 mm. For instance, in TABLE XVI it is shown the impact of length and depth/thickness accuracy for the defect with the highest loss of containment probability (i.e. #1 in TABLE VI).

TABLE XVI. Loss of Containment Probability vs Depth and Length Accuracy

Depth/ Thickness Accuracy	**Length Accuracy**	**#**	**Loss of Containment Probability**							
			2015	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
± 10%	± 15 mm	1	1.21E-06	4.13E-06	1.15E-05	3.08E-05	7.94E-05	1.94E-04	4.61E-04	1.06E-03
± 10%	± 20 mm	1	1.39E-06	4.30E-06	1.19E-05	3.15E-05	8.32E-05	2.17E-04	4.88E-04	1.11E-03
± 15%	± 15 mm	1	3.62E-04	7.03E-04	1.28E-03	2.23E-03	3.65E-03	6.40E-03	1.02E-02	1.64E-02
± 15%	± 20 mm	1(*)	3.98E-04	7.56E-04	1.46E-03	2.30E-03	4.30E-03	6.41E-03	1.05E-02	1.66E-02
± 15%	± 25 mm	1	4.31E-04	7.82E-04	1.50E-03	2.44E-03	4.47E-03	6.75E-03	1.11E-02	1.70E-02
± 20%	± 20 mm	1	4.91E-03	6.81E-03	9.80E-03	1.36E-02	1.86E-02	2.52E-02	3.43E-02	4.27E-02
± 20%	± 25 mm	1	5.13E-03	7.34E-03	1.10E-02	1.41E-02	1.88E-02	2.54E-02	3.54E-02	4.46E-02

(*) Base case scenario, present in TABLE VI as defect #1, has been reported for completeness.

The observed trend is that, as expected, lower is the measurement accuracy (i.e. depth/thickness ± 20% and length ± 25mm), higher are the release probabilities associated to that defect and therefore frequencies of accidental scenarios, and risk level. As shown in TABLE XVI, the depth/thickness accuracy influences the results much more than the length accuracy. If the intelligent pig has a low accuracy (i.e. depth/thickness ± 20% and length ± 25mm), the overall risk level, considering the contribution of loss of containment probability of all defects, is Intolerable already on 2015 (instead of 2017). Based on the same consideration, if the intelligent pig has an high accuracy (i.e. depth/thickness ± 10% and length ± 15mm), the overall risk level is Tolerable (instead of ALARP) on 2015 and becomes Intolerable on 2022 (instead of 2017).

III. CONCLUSIONS

Risk analysis allows to understand if it is possible or not to extend the pipeline design life. Risk level can be ranked for people, environment and asset based on the pipeline internal inspection results. Data gathered by during different inspections can constitute the input data for the risk assessment. Based on two or more consecutive internal inspections, it is possible to evaluate the growth rates of material defects in each direction. When these inspections are misaligned, the gathered data can be elaborated by means of a statistical approach. In this way the actual and future pipeline risk level can be assessed and predicted, allowing pipeline life extension only when truly possible. If the measurements of the inspection vehicle are not so much accurate, an intolerable risk level is found even when the pipeline defects are not so critical: calculated risk level depends strongly on data uncertainty.

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