Corrosion Risk Assessment (CRA) in the Oil and Gas Industry – An Overview and its holistic Approach

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ABSTRACT:

In recent times, the Risk Based Inspection (RBI) engineering approach has been extensively used in the Oil and Gas industries to maintain the plant integrity and thereby continual operation of the assets. Sometimes, the type of corrosion risk and its consequences can be either overlooked in the RBI approach due to inadequate knowledge of the metallurgy, chemical reactions, resulting corrosion mechanisms and the use of an inaccurate statistical approach. This paper analyses the Corrosion Risk Assessment (CRA) and its importance in the RBI approach based on hypothetical data analysed by various statistical techniques. The paper summarises a holistic approach based on corrosion inspection strategies and a statistical approach in the RBI assessment.

KEYWORDS: Corrosion, risk, assessment, qualitative, quantitative, consequences, failure, statistics, probability, reliability.

1. INTRODUCTION:

Risk is the combination of consequences and likelihood of a specific unwanted event (i.e. an incident) resulting from a hazard occurring. In terms of risk, hazard is the product of the likelihood of failure and the consequence of failure i.e. injury or fatalities, material (financial) losses and environmental damage [1].

The implementation of RBI has changed the traditional approach to inspection in oil and gas industries in Australia and other countries [2]. The pipeline risk cost in the oil and gas industries can be calculated by adding all the above consequence cost elements and multiplying it by the predicted frequency of pipeline failure and accident probabilities [3]. RBI is increasingly becoming an interesting and profitable alternative to traditional, frequently performed inspections which may bring added value. Use of RBI also allows operating expenditure to be focused on a few critical elements that will give the greatest return on expenditure. There is a range of commercial software which readily gives the Mean Time To Failure (MTTF) or accelerated life testing of the structure in the RBI analysis. This paper explores the Trend/Forecast, Weibull and the Right Censored Weibull methods in determining the accuracy of the results based on the hypothetical data for a pipeline in oil and gas industry.

1.1 Corrosion Risk Assessment [CRA] – Overview:

Corrosion is a time dependent phenomenon and review of historical failure databases e.g. PARLOC'96 [4] indicates that the major failure modes are internal corrosion and external impact. Corrosion is often illustrated by the logarithmic nature of cumulative leaks versus time data for ageing, unprotected pipelines. It has been reported that pipeline failures caused harm to personnel or fortunate near-misses all over the world [5].

Corrosion might be insidious and takes many forms, but it is manageable. As a rule, the more localized the corrosion, the more rapid the rate of pipe or vessel wall penetration. Ashworth reported that corrosion has accounted for 21% of failures in submarine gas pipelines and erosion and corrosion failure modes account for 24.6% of pipe leakage in process plant [6]. Moreover, it has been reported that 40% of accidental hydrocarbon releases to the environment are corrosion related. Dawson reported that corrosion in ageing onshore and offshore pipelines world-wide has caused pipeline failures and necessitated repair and replacement with costs of millions of dollars [7]. The following failures corrosion mechanisms have been observed in the external and internal of the pipeline is summarised in Table I.

Pipeline - External	**Pipeline - Internal**
Soil	Product, Hydrotest, Mothballing
Localised	Localised
Microbiologically Influenced Corrosion [MIC]	Microbiologically Influenced Corrosion [MIC]
Stray Current	Erosion/Corrosion
Macrocells	Deposit
Corrosion Cracking	Weld Attack
Carbonate/Bicarbonate	Stress Corrosion Cracking [SCC]
Hydrogen Embrittlement	Hydrogen Embrittlement
Hydrogen Pressure Induced Cracking	Hydrogen Pressure Induced Cracking

Table I – Corrosion modes in the External and Internal of the pipeline

Pipeline integrity management is one of the high consequence areas in corrosion control [8]. Pipeline repairs can be very expensive, particularly for offshore pipelines and should be both cost-effective and return the pipeline to its original (construction) condition.

In general, risk assessment software considers both the consequences (health, safety, environmental and financial) and likelihood of failure based on predicted damage mechanisms, equipment susceptibility, and the results of previous inspections [9]. Internal corrosion can be more insidious than external corrosion because it can occur on pipelines where normal operations are expected to cause only minimal internal corrosion. Water that would normally remain suspended in the product can accumulate in these locations and cause internal corrosion in locations where low flow occurs, such as in dead legs, valve bypasses and piping necessitating pigging of the line [10].

In some industries, apart from conventional RBI methods, internal inspection procedures such as "corrosion loops" are used [9]. In this approach, the plant is broken down into sections that are constructed of the same materials and are exposed to the same process conditions. Knowledge of the potential deterioration mechanisms, together with the inspection history, allows inspection programmes to be focused on critical areas within the corrosion loops. The disadvantage in the corrosion loop method is that non-inspectable deterioration mechanisms, such as those that give little indication prior to failure, are very difficult to predict.

1.2 Corrosion Rate and Failure Prediction Models using Software Simulation:

Integrity management requires that operators of liquid pipelines gather all of the construction data, maintenance data, and corrosion data to the condition of distinct segment of each pipeline. In any RBI plans the following strategic elements are considered:

- Corrosive failure mechanisms and rate
- Available remaining life
- Analysis from previous inspection reports regarding the degradation rate
- Process condition variables
- Maximum permissible defect size & Results from the risk assessment

Based on the parameters, it is possible to determine inspection time to determine the corrosion characteristics its rate and extent of damage to the pipelines.

In order to judge the reliability of the statistical approach in this paper, corrosion failure prediction models were created using various statistical techniques. The corrosion rate simulations are carried out by Simple trend, Weibull and Survivability techniques in the following three case studies. Each technique follows its own algorithm where corrosion rate is predicted. The corrosion rate is determined with respect to inspection intervals. A deterioration rate can be estimated for the failure mechanisms that are considered to be inspectable (e.g. corrosion, pitting, SCC, corrosion-erosion etc.). Following calculation of the critical defect size, the predicted service life is determined by extrapolating existing inspection data, where there is a history of deterioration or, by probabilistic methods (e.g. Monte Carlo simulation), where there is no history of deterioration [11]. With most RBI methodologies, by multiplying the predicted remaining service life by a risk-based factor the appropriate inspection interval is determined. This risk-based factor is semi-quantitatively derived using matrices incorporating likelihood, predictability and consequence of failure.

2. CASE STUDIES

CASE STUDY I - CORROSION RATE SIMULATION AND ANALYSIS BY LINEAR TREND/FORECAST ANALYSIS

Calculates, or predicts, a future value by using existing values. The predicted value is a y-value for a given x-value. The known values are existing x-values and y-values, and the new value is predicted by using linear regression. Trend analysis returns values along a linear trend [12]. The plot fits a straight line (using the method of least squares) to the arrays. Table 1 (attached at the end) shows the hypothetical corrosion rate measured in pipeline. The corrosion rate determined by simple trend/forecast analysis is shown in Figure I. Table 2 (attached at the end) shows the calculated corrosion rate for year 14 is 0.318 mm/year from Trend/Forecast analysis.

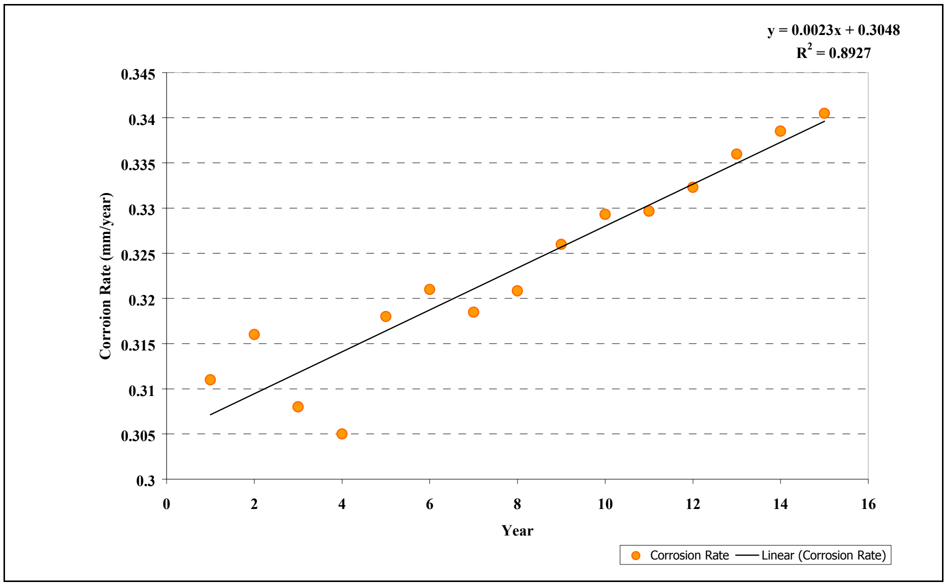

Figure I – Corrosion rate determination by simple Trend/Forecast analysis.

CASE STUDY 2 - CORROSION RATE SIMULATION AND ANALYSIS BY WEIBULL METHOD

Deterministic assessments such as MTTF distributions can be modelled using Weibull statistics which is widely used in reliability engineering and statistics [12]. One can forecast and predict failure and thus evaluate corrective action plans, maintenance plans and cost-effective replacement strategies.

The advantage of the Weibull analysis is the ability to provide more accurate failure analysis and failure forecasts, even with small samples. The fitted line is a graphical representation of the percentiles.

To make the fitted line, the percentiles for the various percents are calculated, based on the Weibull distribution. The associated probabilities are then transformed and used as the y variables. It should be noted here that a set of approximately 95.0% confidence intervals for the fitted line is applied. In general, the closer the points fall to the fitted line, the better the fit. The Anderson-Darling (AD) statistic is used for method. The AD statistic is a measure of how far the plot points fall from the fitted line in a probability plot. A smaller Anderson-Darling statistic indicates that the distribution fits the data better. Figure II shows the Weibull probability plot for hypothetical pipeline whose corrosion rates are measured with time. Data 1 shows at 50% the 95% upper limit Confidence Interval (CI) the approximate corrosion rate measured after 14 years is 0.300 mm/year.

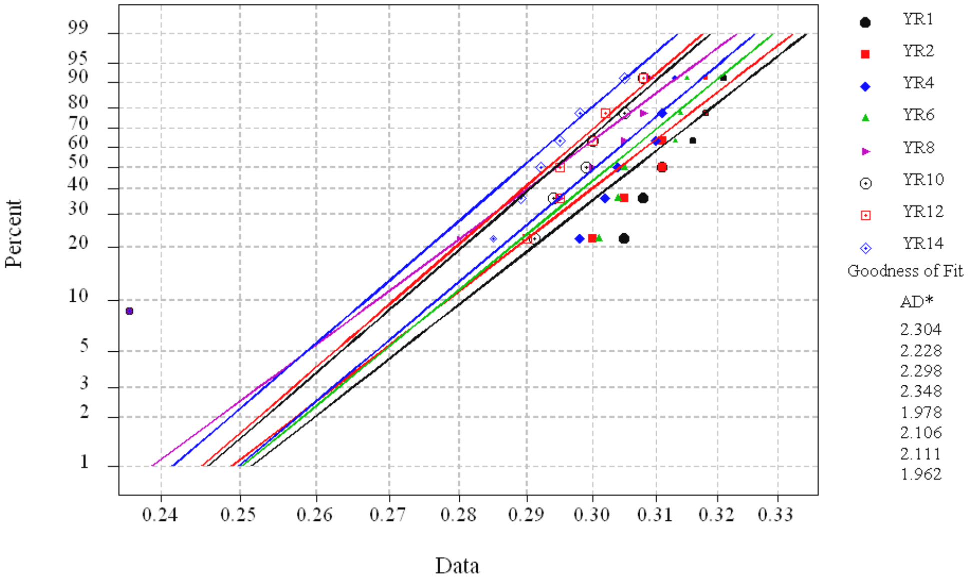

Figure II - Weibull Analysis for Pipeline Corrosion monitored for 14 years.

CASE STUDY 3 - CORROSION RATE SIMULATION AND ANALYSIS BY RELIABILITY AND SURVIVABILITY METHOD

In this case, the corrosion rate data is simulated using reliability and survivability models. By estimating percentiles, survival probabilities, distribution parameters and by drawing survival or hazard plots the more accurately the corrosion rate is determined [12]. To understand the failure-time distribution of a pipeline i.e. corrosion rate, Distribution ID Plot – Right Censored Method is studied. The algorithm was based on the right censoring values where, the inspected pipelines with inaccurate corrosion rate measurement values are censored. In this case, the corrosion rate is known only to be “on the right,” (numbered 1) are included and the suspected anomaly results (numbered 0) are censored as shown in Table III (attached at the end) which gives more reliable corrosion rate values for the inspected item. In order to check the reliability of distribution plot using right censored method, four types of plots such as Weibull, Lognormal base e, Exponential and Normal are generated as shown in Figure 3. In order to compare the accuracy of the corrosion rate from Weibull technique, only Weibull right censored method is considered eventhough the AD value is large compared to the other methods. The Anderson Darling distribution for right censored is 1.405 compared 1.962 for Weibull distribution analysis.

Data 2 shows at 50%, the 95% upper limit Confidence Interval (CI) the approximate corrosion rate measured after 14 years is 0.301 mm/year which is more reliable after censuring the anomaly data.

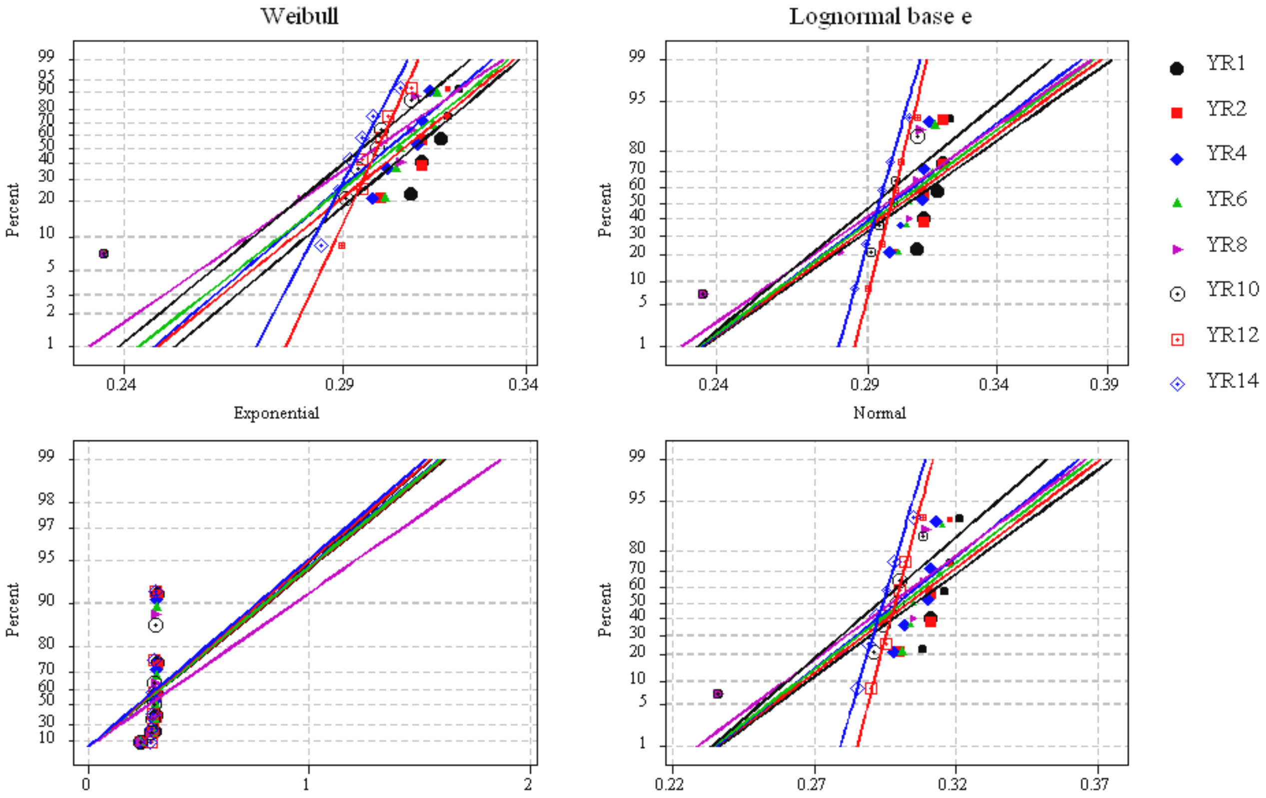

Figure 3 – Four-way Probability Plot for Pipeline Corrosion Risk by Distribution ID with right censoring technique.

3. DISCUSSION:

As the probability of failure increases with time (i.e. time dependent structural degradation), the risk and the cost also increases from previous inspection. It is no secret that inspection and monitoring are not exact particularly with regard to corrosion and corrosion rates. Any measured corrosion rate is merely an approximation of the true rate. The quality of the measured corrosion rate (i.e. how closely it corresponds to the true rate) depends upon two factors.

- The first factor is the quality of the inspection or monitoring technique itself. For inspections, the corrosion rate gained from detailed UT mapping is better than that gained from spot UT, which is again is better than visual estimates [13]. For monitoring, continuous online corrosion monitoring is better than periodic corrosion probe reading which in turn better than periodic corrosion coupon analysis.

- The second factor is how many times, and over what period the measurement is taken. The more inspections/tests are done, the more accurate the corrosion rate prediction is likely to be. Hence the deterministic analysis is helpful in the accurate prediction of the lower risk of failure before the predicted failure date [14]. The cost saving for inspection activities through the use of CRA needs to be balanced which can be achieved by choosing proper statistical/reliability techniques.

In the above three case studies, the corrosion rate measured after 14 years, from the trend analysis is 0.318 mm/year, Weibull method is 0.300 mm/year and Distribution ID Plot – Right Censored Method results is 0.301 mm/year respectively Thus by selecting proper deterministic approach and assessment, the exact CRA can be achieved.

In general, pro-active monitoring methods needs to be maintained and implemented; including good corrosion housekeeping such as routine sampling, on-line monitoring and review of operator logs. This includes proper corrosion monitoring techniques, suitable inhibitor and biocide regime along with the corrosion data will help in predicting reliable asset remaining life. This will give assurance that the inspection intervals determined by application of the RBI methodology remain valid. Thus, inspections, where done are very much for the verification of the predicted. The traditional process data recording should be extended to integrity-related data recording.

Modifying the CMS with implementing RBI methodology will instantaneously provide the pipeline/structure risk which can be useful in the anomaly assessment and also in scheduling inspection interval as shown in Figure IV. Based on the criticality of the CRA, pipeline operators need to develop programs as shown in Figure IV to systematically identify and address risks to the segments of their pipelines that could affect high consequence areas. Models exists for predicting the initiation and growth over time of internal corrosion defects due to CO_2, H_2S, O_2, Organic Acids, Bacterial or a combination for process conditions and potential process upsets needs to be updated and often depending on the environmental conditions and geographical locations of the assets. This will help in interaction between inspection, operation, maintenance and technical personnel giving a more holistic approach to CRA team and integrity management. Apart from the daily integrity assurance actions, regular updates, workshops should be implemented to review the RBI related findings of the previous 12 months and confirm the RBI plan for the coming year.

Corrosion engineers can advise risk management professionals of corrosion matters as required, contribute to the development of procedures and systems [15]. A corrosion engineer's involvement in an RBI analysis will develop an understanding of their role in risk management and the techniques such as risk assessment and process hazard analysis.

Proper CRA methods with relevant analysis techniques will provide the following:

- ✓ Identifiable corrosion damage mechanisms at the incipient state in the pipeline/each equipment.
- ✓ Key process variables affecting pressure equipment where risk can be identified and able to be monitored/controlled.
- ✓ More effective inspection plans to identify damage mechanisms.
- ✓ Auditable process for determining the development of the inspection worklist.
- ✓ Methodology for future inspection plans to be allocated based on risk.
- ✓ Reduction in the number of items included in the workscope.
- ✓ Improved yearly inspection and maintenance costs.
- ✓ Better understanding, and henceforth management, of the factors (design, operating and inspection) that affect the risk of pressure equipment failure by all personnel involved in the process.

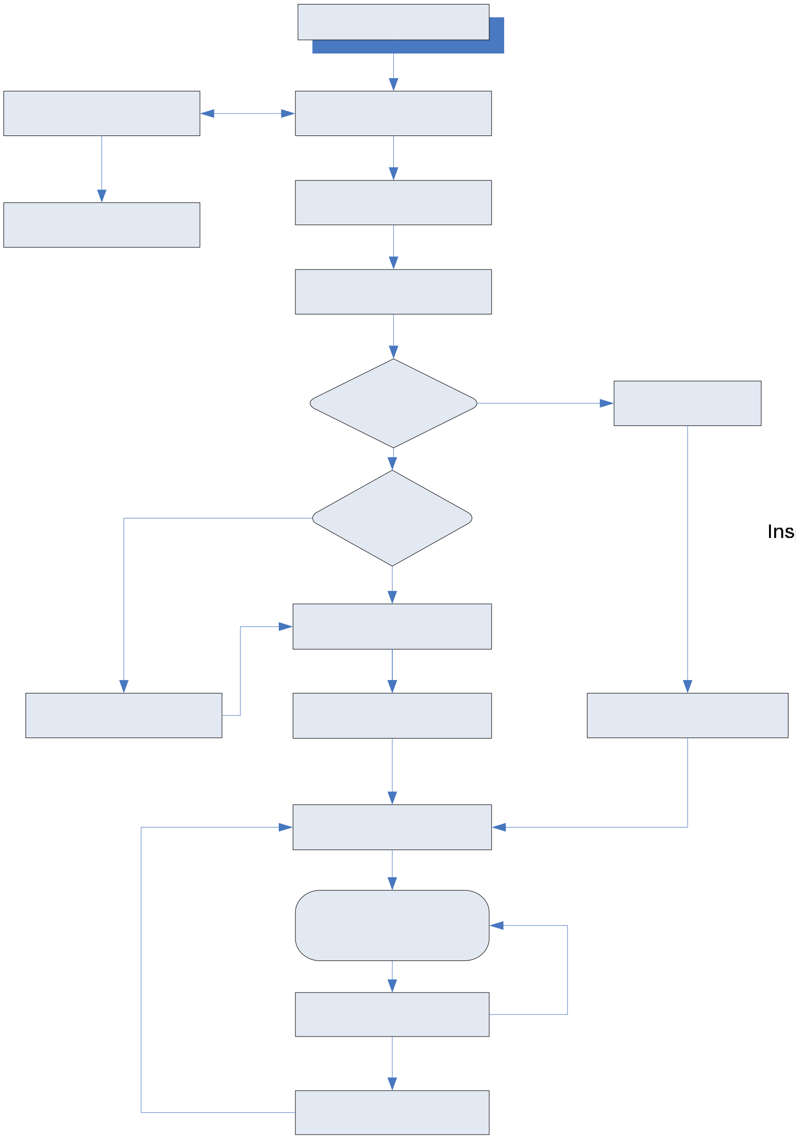

Figure IV – Flow chart for generalised Corrosion Rate Assessment (CRA) integrating the RBI inspection.

4. CONCLUSIONS:

- The identification of potential accidental events and their elimination is critical to the effective risk management of pipeline systems. Choosing proper statistical techniques will provide exact corrosion rates which are critical to the assets.
- Based on the criticality of CRA, pipeline operators need to develop programs to systematically identify and address risks to the segments of their pipelines that could affect "high consequence areas".
- In general, pro-active monitoring methods needs to be maintained and implemented including good corrosion housekeeping such as routine sampling, on-line monitoring and review of the operator logs such as proper corrosion monitoring techniques, suitable inhibitor and biocide regime with the corrosion data will help in predicting reliable asset remaining life.
- The traditional process data recording should be extended to integrity-related data recording. The CMS with implementing RBI methodology will instantaneously provide the pipeline/structure risk which can be useful in the anomaly assessment and also in scheduling inspection interval.
- Variables such as product volumes, product quality and composition, operation temperature, Suspended solids, pipeline inclination angle, water chemistry, in-line inspection logs, Non-Destructive Testing results, corrosion coupons, and P & T profiles needs to be evaluated.
- Regularly updating the for predicting the initiation and growth of corrosion defects models over time to CO_2, H_2S, O_2, Organic Acids, Bacteria for process conditions depending on the environmental conditions and geographical locations are mandatory.

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Corrosion Rate (mm/year)						
YR2	**YR4**	**YR6**	**YR8**	**YR10**	**YR12**	**YR14**
0.311	0.311	0.314	0.309	0.308	0.308	0.305
0.318	0.31	0.315	0.305	0.3	0.302	0.298
0.3	0.298	0.301	0.28	0.291	0.295	0.292
0.305	0.302	0.304	0.295	0.294	0.29	0.289
0.311	0.304	0.305	0.3	0.299	0.295	0.285
0.318	0.313	0.313	0.308	0.305	0.3	0.295
0.236	0.236	0.236	0.236	0.236	0.236	0.236

Table I – Hypothetical Corrosion Rate measured in Pipeline used for the Statistical analysis by Trend/Forecast, Weibull & Distribution ID Plot – Right Censored Method using Weibull method.

Year	**9**	**10**	**11**	**12**	**13**	**14**	**16**	**20**	**22**
Corrosion Rate (mm/year)	0.321000	0.313660	0.314248	0.315061	0.315907	0.318543	0.315795	0.319453	0.320315

Table II – Calculated corrosion rate by Trend/Forecast analysis.

Location	**YR1**	**YR1 Cens**	**YR2**	**YR2 Cens**	**YR4**	**YR4 Cens**	**YR6**	**YR6 Cens**	**YR8**	**YR8 Cens**	**YR10**	**YR10 Cens**	**YR12**	**YR12 Cens**	**YR14**	**YR14 Cens**
Corrosion Rate (mm/year)																
1	0.311	1	0.311	1	0.311	1	0.314	1	0.309	1	0.308	1	0.308	1	0.305	1
2	0.316	1	0.318	1	0.31	1	0.315	1	0.305	1	0.3	1	0.302	1	0.298	1
3	0.308	1	0.3	1	0.298	1	0.301	1	0.28	1	0.291	1	0.295	1	0.292	1
4	0.305	0	0.305	0	0.302	1	0.304	1	0.295	0	0.294	1	0.29	1	0.289	1
5	0.318	1	0.311	1	0.304	0	0.305	1	0.3	0	0.299	1	0.295	1	0.285	1
6	0.321	1	0.318	1	0.313	1	0.313	0	0.308	1	0.305	0	0.3	1	0.295	1
7	0.236	1	0.236	1	0.236	1	0.236	1	0.236	1	0.236	1	0.236	0	0.236	0

Table III – Corrosion Rate simulation and analysis used for reliability and survivability by Distribution ID Plot – Right Censored method.

Data 1 – Data showing for Year 14 of Corrosion Rate by Weibull Distribution Analysis:

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Welcome to Minitab, press F1 for help.
Retrieving worksheet from file: C:\MTBWIN\TRY CORR RISK.MTW
# Worksheet was saved on 13/09/2004 8:44:24 AM
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Results for: TRY CORR RISK.MTW

Distribution Function Analysis

```
Weibull Dist. Parameter Estimates (ML)
Variable: YR14
Shape   23.4419
Scale   0.293693
Goodness of Fit

Anderson-Darling (adjusted) = 1.962

Percentile Estimates

                     95% CI       95% CI
                     Approximate  Approximate
Percent  Percentile  Lower Limit  Upper Limit

 1       0.241362    0.209929     0.277501
 2       0.248659    0.220390     0.280554
 3       0.253053    0.226762     0.282392
 4       0.256234    0.231404     0.283727
 5       0.258742    0.235080     0.284784
 6       0.260820    0.238136     0.285666
 7       0.262600    0.240757     0.286425
 8       0.264160    0.243058     0.287095
 9       0.265552    0.245112     0.287697
10       0.266810    0.246969     0.288245
20       0.275489    0.259747     0.292186
30       0.281057    0.267793     0.294978
40       0.285397    0.273850     0.297430
50       0.289137    0.278797     0.299860
60       0.292600    0.283032     0.302491
70       0.296028    0.286785     0.305568
80       0.299716    0.290262     0.309477
90       0.304330    0.293829     0.315207
91       0.304912    0.294226     0.315986
92       0.305533    0.294638     0.316831
93       0.306206    0.295072     0.317759
94       0.306943    0.295533     0.318792
95       0.307766    0.296032     0.319964
96       0.308710    0.296586     0.321331
97       0.309840    0.297223     0.322993
98       0.311289    0.298005     0.325166
99       0.313463    0.299114     0.328501
```

Data 2 – Data showing for Year 14 of Corrosion Rate Simulation and Analysis by Reliability and Survivability Method: (Based on Distribution ID Plot – Right Censored Method)

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Results for: TRY CORR RISK.MTW

```
Variable:  YR14
Goodness of Fit
Distribution        Anderson-Darling (adj)
Weibull             1.405
Lognormal base e    1.348
Exponential         3.020
Normal              1.351


Table of Percentiles
                                         Standard  95%  Normal  CI
Distribution       Percent  Percentile  Error     Lower         Upper
Weibull             1       0.269254    9.25E-03  0.251722      0.288007
Lognormal base e    1       0.279398    4.79E-03  0.270173      0.288937
Exponential         1       0.003350    1.37E-03  0.001505      0.007457
Normal              1       0.279044    5.05E-03  0.269141      0.288947

Weibull             5       0.278853    6.75E-03  0.265934      0.292400
Lognormal base e    5       0.283579    3.87E-03  0.276093      0.291267
Exponential         5       0.017098    6.98E-03  0.007681      0.038058
Normal              5       0.283425    4.03E-03  0.275535      0.291316

Weibull            10       0.283201    5.63E-03  0.272373      0.294459
Lognormal base e   10       0.285833    3.43E-03  0.279184      0.292640
Exponential        10       0.035120    1.43E-02  0.015778      0.078173
Normal             10       0.285761    3.54E-03  0.278819      0.292703

Weibull            50       0.294903    3.06E-03  0.288968      0.300960
Lognormal base e   50       0.293930    2.62E-03  0.288848      0.299101
Exponential        50       0.231049    9.43E-02  0.103801      0.514287
Normal             50       0.294000    2.62E-03  0.288856      0.299144

Table of MTTF
                              Standard  95%  Normal  CI
Distribution        Mean      Error     Lower        Upper
Weibull             0.293681  0.003239  0.287400     0.300099
Lognormal base e    0.294000  0.002616  0.288916     0.299173
Exponential         0.333333  0.136083  0.149754     0.741960
Normal              0.294000  0.002625  0.288856     0.299144
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