RISK BASED INSPECTION (RBI) ASSESSMENT AT ABOVEGROUND STORAGE TANKS (ASTs)

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ABSTRACT

Within many companies, there is a maintenance backlog. Tanks were always seen as the “ugly duck”. Not much effort (budget). Not much know-how of how to inspect and maintain. Around 1990, the first guidelines were issued. API=inspection and repair driven; EEMUA=preventive driven.
Early 2000 many companies are cost cutting, however amount of work increase (effort) due to aging. Question is whether Risk-based inspection (RBI) can solve the backlog. The RBI methodology will optimize the in-service period on basis of the condition and repairs done. It will not help you to postpone shutdowns but assist you in the decision making process and gives you confidence.
RBI provides a prudent assignment of resources to assess and maintain equipment technical integrity based on their risk levels. Moreover, API 653, Tank Inspection, Repair, Alteration, and Reconstruction, has identified the value of RBI for storage tanks in terms of determining inspection strategies as well as inspection intervals. It emphasizes that these RBI assessments on ASTs must be reviewed for any changes in risk, at least every 10 years, or more often, as changes occur with respect to tank design or foundation as well as the assumptions taken.
This paper presents the step by step implementation of API RBI technology to conduct risk based assessment on four bulk plants for 10 storage tanks in diesel and gasoline services. In this assessment, the API-RBI methodology was used based on API Publication 581, 2nd Edition, September 2008 and API-RBI software version 8.03.03.
Risk assessment for tanks shows applicability to extend the TURNAROUND interval from 10 years to 15 years provided that all recommendations of this assessment are followed. Based on an increased TURNAROUND interval from 10 years to 15 years, saving of approximately $15,000.00 USD/Year for each tank is estimated.

Keywords: Aboveground Storage Tanks, Risk Based Inspection, TURNAROUND, required tank and foundation design data, operating data, historical data etc.

Note: The presented case study of conducting RBI assessment at aboveground storage tanks has been jointly completed by Saudi Aramco and Velosi teams.

INTRODUCTION

For any asset operating under specified conditions, asset integrity is achieved when the risk of a failure occurring which would endanger the safety of personnel, the natural environment or asset value has been reduced to ALARP. Contrary to popular belief, in the context of reliability and integrity, optimization is not about finding the minimum total cost. It is about finding the actions to achieve the desired level of risk. It so happens that this often produces the lowest total cost almost as a by-product. Maintenance planning is therefore directed at finding tasks that bring the risks to ALARP or lower. Sequentially, RBI has been developed during last couple of decades in order to optimize inspection and maintenance efforts for each and every piece of equipment in the plant. The intent of implementing RBI methodology is to allow industry to efficiently manage plant integrity. RBI is used to manage the overall risk of a plant by focusing inspection efforts on the process equipment with the highest risk. It provides the basis for managing risk by making a calculated decision on inspection frequency, level of detail, and types of NDE. In most plants, a large percent of the total unit risk will be concentrated in a relatively small percent of the equipment items. These potential high risk components may require greater attention, may be through a revised inspection plan.

This paper facilitates sharing of knowledge on the methodology by explaining step by step procedure to carry out API-RBI assessment at aboveground storage tanks, including required design, operating, historical data for tank itself and foundation as well. The API-RBI study has been completed based on API Publication RP-580 & 581 and API-RBI software version 8.03.03.

RBI OF ABOVEGROUND STORAGE TANKS

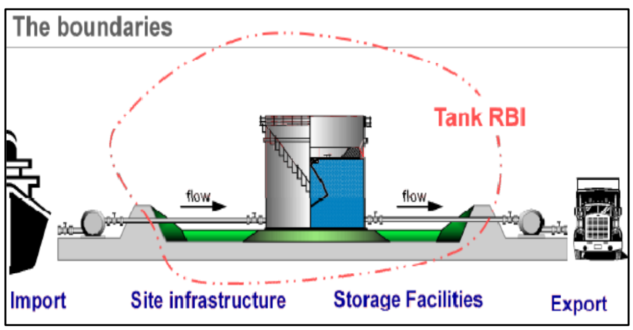

Figure 1 - The Boundary of the RBI Assessment

Conducting RBI on a storage tank requires three basic processes:

1. Data collection and condition review
2. Criticality assessment; involves preparation of corrosion loops by identifying potential damage mechanism, development of inventory groups and calculation of risk
3. Inspection planning and implementation

1. DATA COLLECTION AND REVIEW

The following data is required for quantitative risk assessment of the tank:

- Process and Instrument Diagrams (P&ID's)
- Process Flow Diagrams-PFD's (with flow, mass balance and stream data)
- Heat and Material Balance Sheet/drawings (if not given on PFDs)
- Material selection drawings
- Tank data sheets and mechanical drawings
- Tank foundation design & construction data
- Tank CP data and CP potential surveys reports
- Plant Process Description/operating manual
- Plant Plot Plan

- Financial data for cost of plant shut down (lost production) and daily production cost
- Average cost of process plant equipment split down per area
- Painting & Coating Specification
- TURNAROUND reports (Failure/Replacement/Maintenance/Repair /Modification Records) and modification data (if any)
- Inspection History Data for equipment and piping systems (especially OSI 3in1 sheets and OSI drawings).

Documents for Condition Review

Along with tank construction, operating and historical data, the following documents/results should be kept in view for better results of risk assessment:

- Close Monitoring Survey results for CP system. This to ensure maintaining acceptable level of protection.
- Sulphate Reducing Bacteria (SRB) test results and effectiveness of biocide treatment for the water in tank product side. Normally, SRB tests should be carried out at least twice a year to have a clue for their presence and the severity of Microbiological Induced Corrosion (MIC).
- Magnetic Flux Leakage (MFL) results
- Acoustic emission test results for tank bottom
- Regular water draw-off, rigorous operational procedures
- Effective Internal and external coating program; to ensure the application of most compatible coating system and following a disciplined QA/QC procedure while applying the coatings. Apart from normal practice, it would be better if top shell course is coated from inner side in order to avoid aboveground corrosion due to swing position of the floating roof during the normal operation.

2. CRITICALITY ASSESSMENT

2.1 Prepare The Software Database

API RBI divides storage tank into two sections for risk assessment:

(i) Bottom - consisting of the annular plates and floor island plates
(ii) Shell Course/s - the tank shell strakes

Basic design, operating and historical inspection data especially thickness and corrosion rate measurements are populated into import spread sheets, details of import spreadsheets are given below in section 2.4. The preparation of the tank database for the first time is an extensive process. However, once completed, re-analysis and "What-if?" scenarios are relatively straightforward. As far as possible, electronic data sources are used, both to speed up the data assembly process and to minimize data entry errors.

2.2 Preparation of Corrosion Loops By Identifying Potential Damage Mechanism

The aim of establishing the corrosion loops is addressing the AST deterioration mechanisms that pose a threat to the integrity of the structure. Corrosion loops are normally prepared on the Process Flow Diagrams (PFDs) by identifying applicable damage mechanisms for all components of tank in accordance with API 571 based on fluid stream, material of construction, operating conditions and % of corrosive ingredients like H_2S, CO_2 etc. A typical corrosion loop drawing in Figure-3 shows the unique color for each corrosion loop and encircled number for the identified damage mechanisms as per API 571.

The purpose of corrosion loop is to graphically represent the identification of those damage mechanisms which develop over a period of time, gradually weakening the system boundary and integrity of components until failure occurs. A clear understanding of expected and possible damage mechanisms for equipment is crucial to conduct the risk assessment and apply suitable inspection methods to mitigate risk posed by them. Identification of these damage mechanisms is carried out in accordance with NACE (National Association of Corrosion Engineers), API 571, API 572, API 574, API 579, API 580 and API 581.

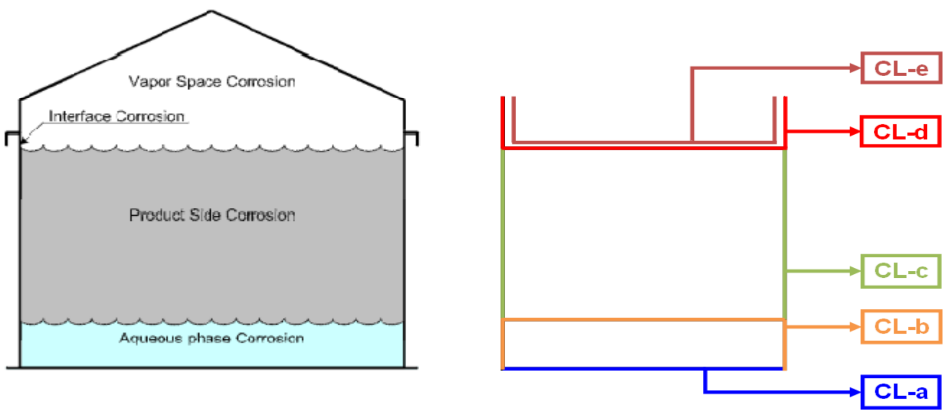

Figure 2 - Corrosion Loop Sub-division for Tank

In order to aid a structured approach to the tanks under assessment, corrosion loop for tank is subdivided into five (05) sub-loops as under:

1. CL-a for Tank Bottom
2. CL-b for Tank Bottom Shell
3. CL-c for Tank Middle Courses
4. CL-d for Tank Upper Course
5. CL-e for Tank Roof

The damage mechanisms include floor corrosion (where Cathodic protection and drainage issues are important), internal corrosion (where the contents of the tank, the presence of species such as Sulphate Reducing Bacteria and temperature controlled corrosion rates) and non-corrosion related mechanisms such as differential settlement.

In detail, other relevant damage mechanisms could be as under:

- Aboveground Corrosion (applicable at inner side of the top shell course, on the roof and subject to effective coating program, on the external side of the shell courses)
- Microbiologically Induced Corrosion (MIC), (applicable at product side of the tank bottom when tank has crude with hydrocarbon contaminants and water present)
- Soil Corrosion, (applicable at soil side of the tank bottom)
- HCl Corrosion- related to crude heating

- Mechanical fatigue - at shell corner joint with regular tank filling and emptying
- Corrosion under insulation - for insulated crude tanks with heavy crude
- Wet H_2S damage etc.

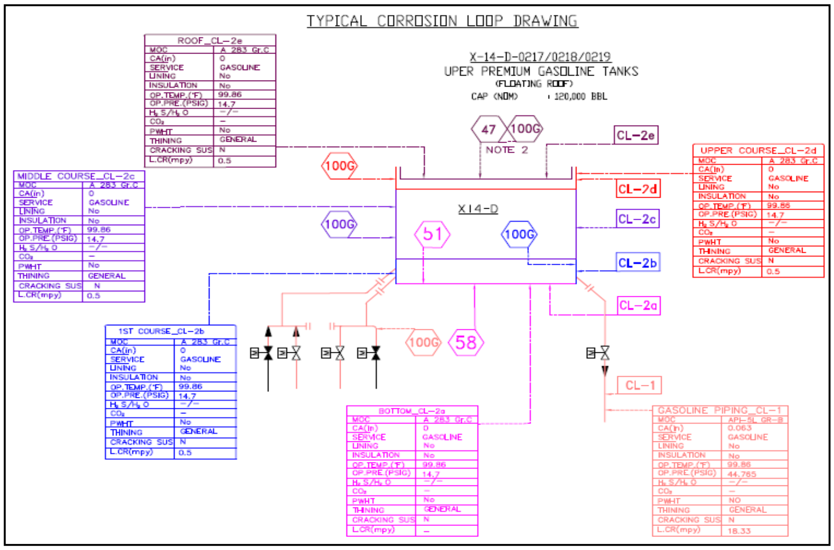

Figure 3 - Typical Corrosion Loop Drawing for Tank

2.3 Development of Inventory Groups

Inventory group is used to determine the mass/volume of fluid that could realistically be released in the event of a leak. The inventory group is used to designate a grouping of equipment that can be remotely isolated from other sections of the plant in an emergency situation. When a component or piece of equipment is evaluated, its inventory is combined with inventory from other attached equipment that can realistically contribute fluid mass to the component that is leaking.

Moreover, the software estimates available mass as the lesser of two quantities:

- The mass within the component being evaluated plus the mass that can be added to it within three minutes from the surrounding Inventory Group, assuming the same flow rate from the leaking equipment item, but limited to an 8-inch leak in the case of ruptures.
- The total mass (lbs), vapor volume (ft^3) and liquid volume (ft^3) of the fluid in the Inventory Group associated with the component is also being evaluated.

The typical inventory group drawing is presented in Figure-4 below.

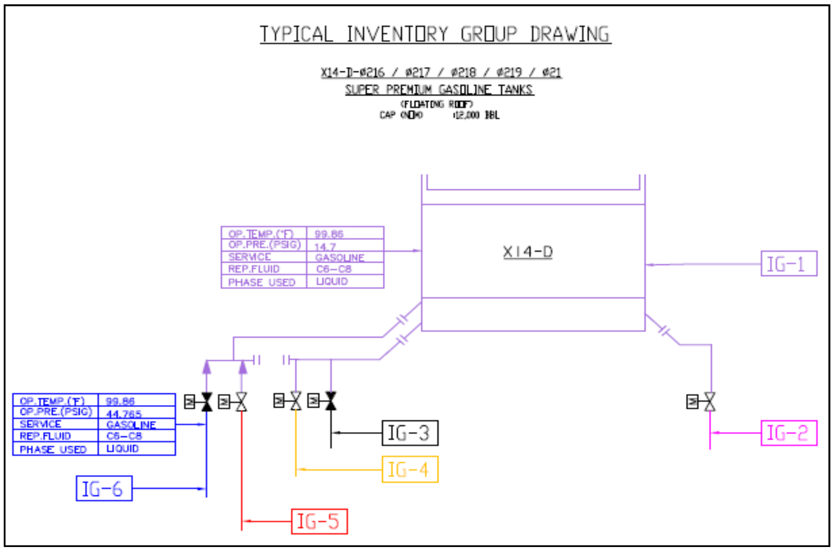

Figure 4 - Typical Inventory Group Drawing for Tank

2.4 Calculating POF and COF

The following RBI import spreadsheets are to be completed after the, identification of damage mechanisms, preparation of corrosion loops and inventory groups:

- <u>Import\basic.rbx</u>
  This sheet contains data like tank design/construction, operating conditions, thickness measurement results, corrosion rates etc.
- <u>Import\tank.rbx</u>
  This sheet contains data like tank design, repaired/maintenance, fluid levels, environment sensitivity, dike information, foundation soil information, CP adjustment, product and soil side corrosion rates, water draw off, steam coil adjustment etc.
- <u>Import\tankdetails.rbx</u>
  This sheet contains data like tank design, repaired/maintenance, shell course details, operating liquid levels etc.
- <u>Import\bottomsuppliment.rbx</u>
  This sheet contains data like tank bottom plate design, repaired/maintenance, environment sensitivity, dike information, foundation soil information, CP adjustment, product and soil side corrosion rates, water draw off, steam coil adjustment etc. Further, the details of bottom plate data required for analysis can be reviewed from Table 2.B.14.1 to 14 of API RP 581.

Tanks are classified as High Environmental Sensitivity due to their proximity to the community underground water source. The foundation type is set to Coarse sand and all tanks are equipped with Release Prevention barriers as well.

This is very important to note that consequence calculation basis is "FINANCIAL" for the tank component i.e. tank bottom and shell courses. Further, API RBI software is not being developed to generate the risk matrix when financial model is running. Thus, one has to follow the details provided by Table 4.2 of API_RP_581_2nd_Ed_Sept_2008 to judge the COF and POF. It is very important to note;

$D_{f\text{-}total}$ = Total Damage Factor / sum of DFs calculated for all Damages

FC = Financial Consequences / Cost ($)

For risk matrix, POF can be accessed directly from "Total DF" and COF from "Financial Cost" from exported "Inspection plan and Risk analysis export sheets". Further, one may have Financial Risk Matrix COF breakdown;

- Break down point-1 : $10,000
- Break down point-2 : $100,000
- Break down point-3 : $1,000,000
- Break down point-4 : $10,000,000

This breakdown in the financial risk matrix can be reviewed under case study.

3. INSPECTION PLANNING AND IMPLEMENTATION

Based on this risk ranking, an inspection plan is developed based on the criticalities evaluated in the current state and future states of the tank for both two sections i.e. tank shell courses and bottom plate. Now, one can decide whether to:

- Remove the equipment from service and conduct required inspections (this is applicable if equipment is showing high risk and there are no suitable on-line inspection methods to reduce the risk level).
- Apply appropriate on-line inspection methods for equipment to reduce the risk level.
- Add equipment in the inspection scope during Turnaround to aid future risk assessments.
- Leave equipment on-line inspection and/or Turnaround inspection scope at current level.
- Reduce equipment on-line inspection and/or Turnaround inspection scope from current level.

CASE STUDY

API RBI assessment was carried out on four bulk plants for newly contracted 10 storage tanks of diesel and gasoline as shown below in Table-1.

Table 1 - Tanks Commissioning Dates

Sr. No.	Area	Tanks	Service	Start Date	Capacity (BBLS)
1	X-14	T-217	Super Premium Gasoline	June, 2005	120,000
2	X-14	T-218	Super Premium Gasoline	January, 2006	120,000
3	X-14	T-219	Super Premium Gasoline	January, 2006	120,000
4	X-15	T-364	Premium Gasoline	June, 2005	35,000
5	X-15	T-367	Premium Gasoline	June, 2007	35,000
6	X-15	T-368	Premium Gasoline	June, 2007	35,000
7	X-16	T-103	Diesel	January, 2005	75,000
8	X-16	T-104	Diesel	January, 2005	75,000
9	X-18	T-115	Premium Gasoline	June, 2005	20,000
10	X-18	T-117	Premium Gasoline	January, 2006	20,000

The assessment is completed by identifying the potential damage mechanisms, corrosion loops, inventory groups, risk levels and recommendations for optimizing future inspections. The following points are important to note while completing this assessment:

- Each tank was subdivided into two section i.e. shell course and bottom plate which resulted in 74 components in the database for 10 ASTs.
- Each tank was given a corrosion loop which as subdivided into five sub-corrosion loops as explained above.
- Inventory group has been identified based on remote isolation locations.
- RBI import sheets were populated and imported into API RBI software to run financial based risk assessment.
- Risk calculations were made for current TURNAROUND *overhaul* interval of 10 years and then for extended TURNAROUND interval of 15years.
- In absence of inspection history (thickness measurements) of tank bottom plate, analysis is carried out by using calculated corrosion rates which should be updated once the thickness measurements are available.

CORROSION ASSESSMENT

The damage mechanisms associated with the AST in question are related to thinning (internal and external) (i.e. product side and soil side). Along with expertise of industry specialists, API 571 and 581 were used to identify the potential damage mechanisms. No cracking mechanisms were anticipated.

Product side corrosion is normally due to the presence of salts, Micro-biological Induced Corrosion (MIC), dissolved H_2S, and dissolved O_2, water bottom layers (brine) and various other impurities. Product side corrosion can be mitigated by linings, better mixing to avoid deposits and proper foundation design to minimize local settlements.

Corrosion on the Soil side is normally due to moisture retained in soil and impurities in tank pad materials and is generally localized. Soil side bottom corrosion can be mitigated by proper drainage, properly designed and maintained Cathodic Protection and sound tanks pad design.

Since tanks were newly constructed and thickness measurement inspection history records were not available for *tank bottom*, thus corrosion rates were calculated by using following assumptions given in Table-2 that have been populated in “Thinning Supplement” tab of API RBI 8.03.03 for tanks and calculated corrosion rates for tank bottoms are given in Table-3.

Table 2 - Assumptions for Tank Bottom

Category	Setting
Damage Type	Thinning Type – Thinning supplement
BM Corrosion Rate	Calculated
Tank Bottom Type Adj.	RPB PER API650
Tank Cathodic Protection Adj.	YES PER API651 *(The Cathodic protection is implemented on these tanks internally and externally as per tank survey data)*
Tank Drainage Adj.	One Third Frequently Under Water
Tank Pad Adj.	CONSTRUCTION GRADE SAND
Tank Product Base Rate	Yes
Product Side Corrosion Rate	2mpy
Tank Product Condition Flag Adj.	WET
Tank Soil Base Rate	Yes
Soil Side Corrosion Rate	5 mpy
Tank Soil Resistivity Adj.	500-1000
Tank Steam Coil Adj.	No
Tank Water Draw Off Adj.	Yes
Tank Welded Flag	Yes

Table 3 - Calculated Corrosion Rates for Tank Bottom

Component	Service	BM Corrosion Rate	Total BM Corrosion Rate *(mpy)*
T-0217-Bottom-CL2a	Super Premium Gasoline	Calculated	10.11175
T-0218-Bottom-CL2a	Super Premium Gasoline	Calculated	10.11175
T-0219-Bottom-CL2a	Super Premium Gasoline	Calculated	10.11175
T-0364-Bottom-CL4a	Premium Gasoline	Calculated	10.11175
T-0367-Bottom-CL4a	Premium Gasoline	Calculated	10.11175
T-0368-Bottom-CL4a	Premium Gasoline	Calculated	10.11175
T-0103-Bottom-CL6a	Diesel	Calculated	10.11175
T-0104-Bottom-CL6a	Diesel	Calculated	10.11175
T-0115-Bottom-CL8a	Premium Gasoline	Calculated	10.11175
T-0117-Bottom-CL8a	Premium Gasoline	Calculated	10.11175

The summary of the Financial-risk analysis results with an aim of extending Turnaround *overhaul* interval from 10 to 15 years are presented in Figures - 5 and 6 on the risk matrixes.

RISK ANALYSIS

A risk projection for all tanks is carried out to evaluate future risk rankings for current TURNAROUND *overhaul* interval of 10 years and proposed TURNAROUND new *overhaul* interval of 15 years. The details can be reviewed as under:

A- **<u>Comparison of Current and Future Risk in 2015 (with 10 year TURNAROUND) interval)</u>**

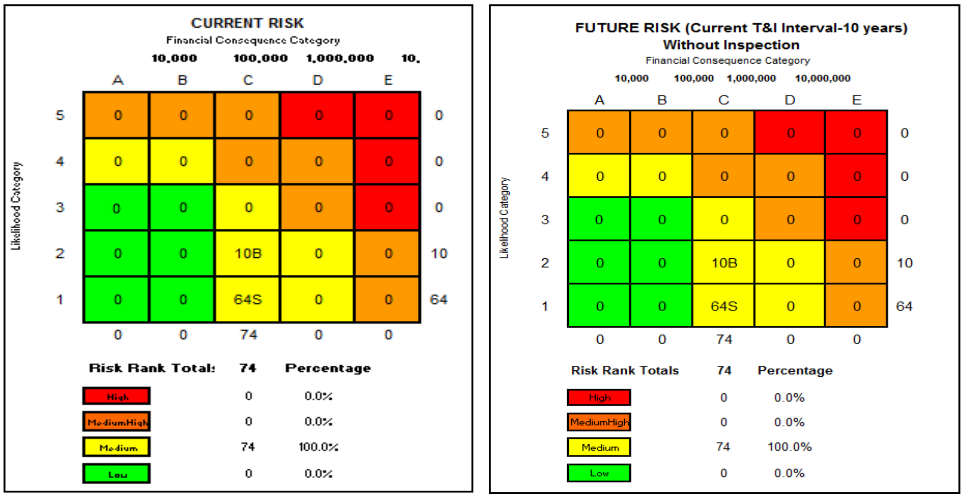

Figure 5 - Risk Comparison between Current (2012) and Future with 10-Years Turnaround Interval

Note: *"**B**" represents the Bottom/Floor and "**S**" represents the Shell courses of the tank in the risk matrix.*

The main observations from Figure 5 are as follows:

- The overall current risk distribution for seventy four (74) components tanks shows zero components at HIGH RISK, zero components at MEDIUM HIGH RISK, seventy four (74) components (100%) in the MEDIUM RISK and zero components at LOW RISK category.
- The comparison of current and overall future risk distribution shows that there is no change in risk levels up to 10 years without doing any inspection. All tanks floors, ten (10) components, are at POF-2 whereas all other components (tank shell courses) are at POF-1.

B- Comparison of Future Risk for Current TURNAROUND Interval (10 yrs) without Inspection and Proposed TURNAROUND Interval (15 yrs) with Inspection.

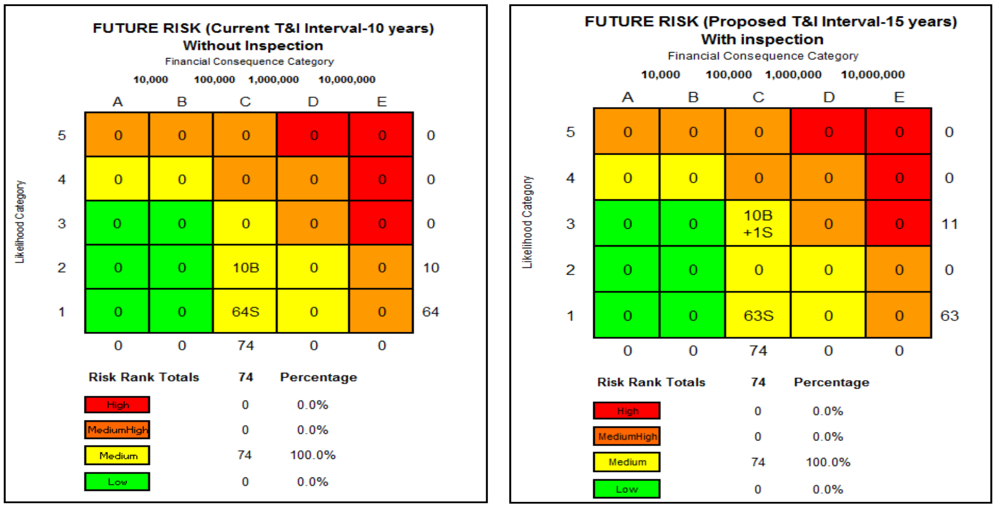

Figure 6 - Risk Comparison with 5-Years TURNAROUND Extension

Note: *"**B**" represents the Bottom/Floor and "**S**" represents the Shell course of the tank in the risk matrix.*

The main observations from Figure 6 are as follows:

- The overall future risk distribution with inspection (at proposed Turnaround interval-15years) for seventy four (74) components tanks shows zero components at HIGH RISK, zero components at MEDIUM HIGH RISK, seventy four (74) components (100%) at MEDIUM RISK and zero components at LOW RISK category. Ten (10) components are the tank bottom plates at POF-3, one (1) shell course (D-0115-Course 2; due to high corrosion rate of 10.9 mpy) at POF-3, whereas all other components (tank shell courses) are at POF-1.

- From the above comparison, at proposed TURNAROUND *Overhaul* interval of 15 years, if inspection are performed then ten (10) tanks bottom plates and one (1) tank shell course will stay at MEDIUM RISK. Hence, ***there is an option of extending the TURNAROUND overhaul interval from 10 to 15 years***. However, it is highly recommended to perform all inspection as per calculated inspection plan in order to lower or at least maintain the risk at same level.

- Since this RBI analysis has been carried out based on the "calculated corrosion rate" due to unavailability of measured corrosion rates (since, tanks are newly constructed). So it is highly recommended to updated database for measured corrosion rates and rerun the risk calculation based on true corrosion rate values instead of estimated one.

GRAPHICAL PRESENTATION OF TANK ANALYSIS

Tank bottoms are selected to develop the risk plot by using probability and consequences against different risk targets *($ 5000, $10,000 and $20,000)* which are showing the placement of tanks bottom on charts in Figure-7 and Figure-8.

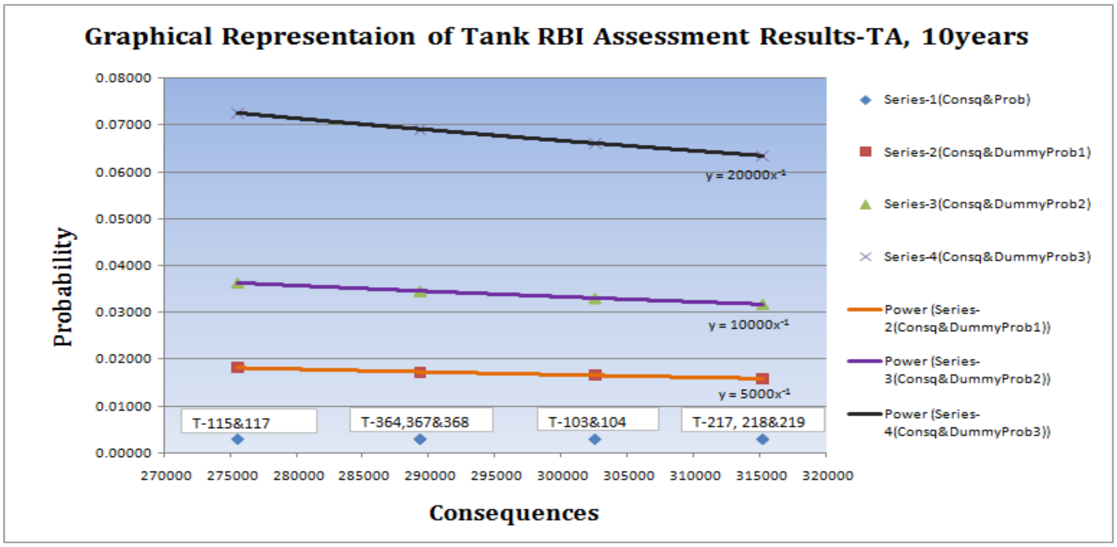

Figure 7 - Tank's Graphical Representation for Current TURNAROUND – 10 years

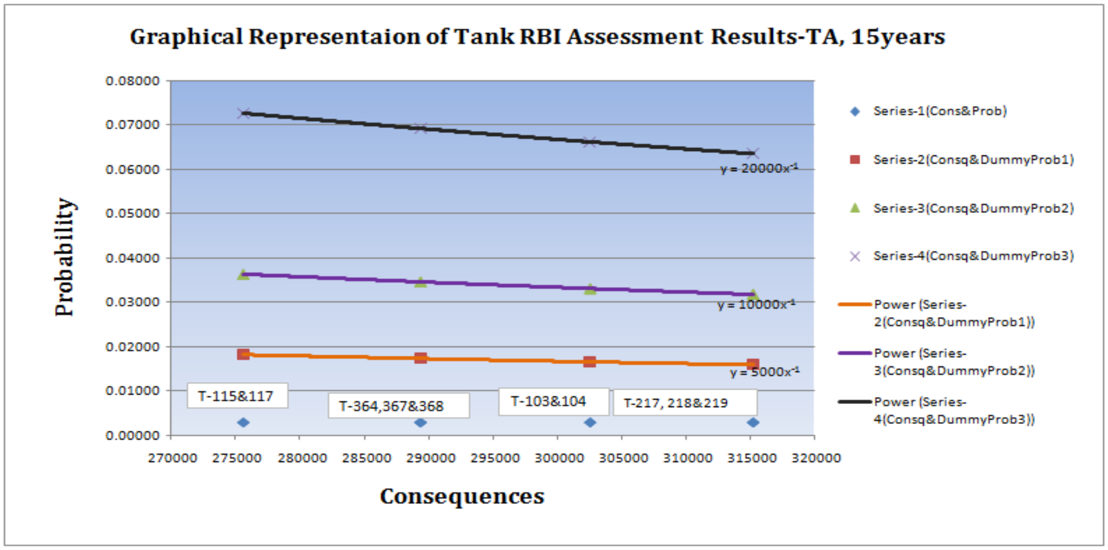

Figure 8 - Tank's Graphical Representation for Proposed TURNAROUND – 15 years

FINANCIAL BENEFITS

Based on an increased Turnaround interval from 10 years to 15 years for tanks, a saving of approximately $15,000.00 USD/Year for each tank is derived from the following information:

- Single TURNAROUND *overhaul* total cost for one tank is approx. 450,000.00 USD

Turnaround Costs

- Turnaround Maintenance/Inspection Cost approx. $450,000.00 per Turnaround.
- Current Turnaround cost per year is :
  Turnaround Cost/Turnaround Interval = $450,000.00/10 Years (current Turnaround interval) = $45,000.00 USD/Year
- New Turnaround Cost per year would be:
  Turnaround Cost / Turnaround Interval = $450,000.00/15 Years (the new proposed Turnaround interval) = $30,000.00 USD/Year
- Turnaround Cost Avoidance for one tank per Year = 45,000.00- 30,000.00
  = $15,000.00 USD/Year per tank

The business interruption cost has not been considered in this assessment because of the high redundancy level in the plant where there is no impact on the production, in case any tank is taken out of service for maintenance, TURNAROUND or any other activity.

RECOMMENDATIONS

Based on RBI risk analysis results, the following are the recommendations:

1. Based on the risk assessment findings and in order to extend the Turnaround cycle from ten (10) to fifteen (15) years, the following recommendations need to be followed:
   a) Perform Close Monitoring Survey for CP system to ensure maintaining acceptable level of protection.
   b) Perform Sulphate Reducing Bacteria (SRB) test for the water in tank product side at least twice a year to have a clue for their presence and the severity of Microbiological Induced Corrosion (MIC). Then regular biocide treatment should be conducted as required.
   c) Perform Acoustic emission test for each tank prior to applying for an equipment inspection schedule deviation.
   d) Regular water draw-off, rigorous procedure shall be in place.
   e) Effective Internal and external coating program to ensure the application of most compatible coating system and following a disciplined QA/QC procedure while applying the coatings. Apart from normal practice, it would be better if top shell course is coated from inner side in order to avoid above ground corrosion due to swing position of the floating roof during the normal operation.
   f) Perform all inspections, as recommended in Appendix-6.

2. Magnetic Flux Leakage (MFL) should be carried out and properly recorded as per mandatory tank Turnaround activity and inspection requirement, which could be used in the future RBI analysis.

3. Due to unavailability of tank design, construction and foundation data, this assessment is carried out on the basis of the certain assumptions. It is highly recommended that API RBI database and assessment should be updated as soon as actual data becomes available for future RBI analysis.
4. Proper internal coating program & routine water draining procedure by Operation should be maintained in order to avoid any product side corrosion especially caused by Sulphate Reducing Bacteria (SRB).
5. To ensure that RBI is effectively and continuously implemented, perform all inspections, as recommended by calculated inspection plan.
6. It is recommended that top shell course should be coated from inner side in order to avoid above ground corrosion.
7. Optimize the OSI for low risk category components.

CONCLUSIONS

RBI is a systematic tool of inspection cost-effective management by preparing effective inspection plan especially with a history of active damage and focus on high risk components. The main risk drivers and contributor for tank bottom are corrosion rates (i.e., soil side corrosion and general internal corrosion), environmental sensitivity, type of foundation and the presence of release prevention barrier (RPB).

Based on Risk projections, the *overhaul* frequency for the storage tanks in question can be extended from ten (10) years to fifteen (15) years interval if RBI assessment recommendations are followed. Consequently financial benefits of approximately $15,000.00 USD/Year can be realized.

REFERENCES

[1] *American Petroleum Institute, API RBI RP 580.*
[2] *American Petroleum Institute, API RBI Technology 581*
[3] *API 571, Damage Mechanism affecting fixed equipment in the Refining Industry.*
[4] *API 650, Welded Steel Tanks for Oil storage*
[5] *API 653, Tank Inspection, Repair, Alteration, and Reconstruction*