WHITEPAPER

3RD EDITION OF THE API 581 RBI STANDARD AND APPLICATION WITHIN THE FRENCH PROCESS INDUSTRIES

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ABSTRACT

The Risk Based Inspection (RBI) methodology is widely used internationally, especially in the Oil & Gas Industry and is well accepted in France. Several RBI projects have been reported in the literature demonstrating the strengths of the approach in controlling risks and optimising inspection schedules. API RP 581 is a well-established methodology for conducting RBI in the downstream industry and the 3rd edition of the standard has just been published in April 2016. This paper examines the new features of the 3rd edition particularly for internal and external thinning and corrosion under insulation and it also discusses a case study of application of this latest RBI methodology in France. This happens in the context of a recognised inspection service operating under the French regulatory framework. The paper is interested in the challenges of application of the RBI methodology in this context when inspection planning needs to combine risk calculations with regulatory constraints. The quantitative approach of API RP 581 proves to be a good basis for optimised, consistent and "automatic" scheduling of inspections and can be made to work under the existing regulations.

Key Words: Risk assessment, risk-based inspection, probability of failure, consequence of failure, inspection planning

INTRODUCTION

The risk based inspection (RBI) approach is currently well established and widely used in the Oil & Gas, Refining, Petrochemical and Chemical Industries. Figure 1 shows a typical RBI process taken from the latest edition of API RP 580 (2016) [1] based on equipment risk calculations for a number of scenarios of loss of containment. The risk assessment, including consequence of failure and likelihood of failure, ranks items according to risk and allows elaboration of an effective inspection plan, including inspection methods, timing and coverage. This is translated into a detailed inspection plan, which is executed and the results are evaluated and fed back into the next cycle of risk assessment and inspection planning. In addition to inspection, other mitigation measures may need to be taken if the risk is still high or if the inspection identifies specific issues.

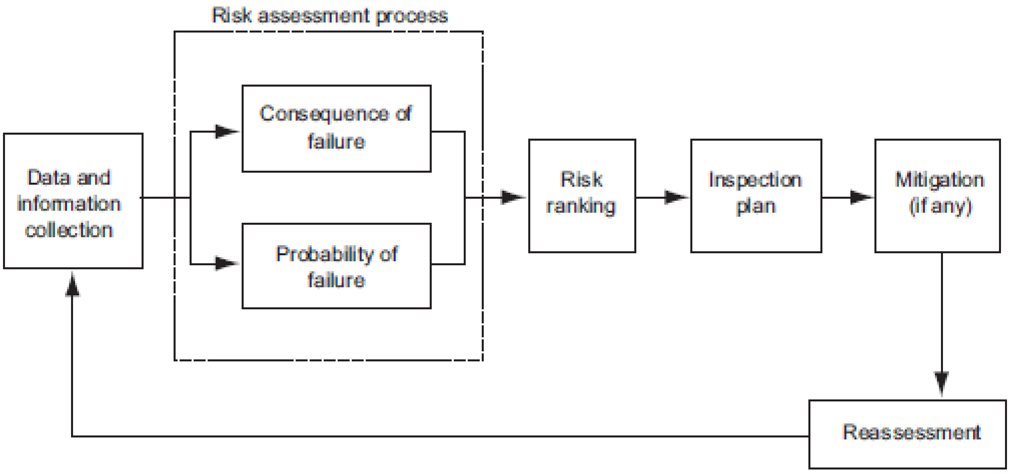


Figure 1: Typical Risk Based Inspection Process

The RBI application benefits are well known and they are summarized by API RP 580 (2016) [1]:

- RBI facilitates the development of optimised plans (inspection or mitigation plans) to manage risks on an equipment level
- RBI may provide an overall reduction in risk for the facilities and equipment assessed
- RBI provides an acceptance/understanding of the current risk
- RBI may identify equipment items that do not require inspection or some other form of mitigation. Inspection & maintenance activities can be focused and more cost effective. This results in a significant reduction in the amount of inspection data that is collected. RBI inspection plans may also result in cost reductions.

API RP 580 (2016) [1] documents, at a relatively high level, the essential elements of a "quality" Risk Based Inspection analysis in the hydrocarbon and chemical process industry and allows different types of approaches such as qualitative RBI or quantitative RBI. ASME PCC-3 2007 [5] is an alternative document to API 580, possibly with more details in specific areas.

A number of other documents have been developed which try to define RBI for specific sectors or for specific geographical areas. A joint industry project produced DNV RP G101 ([8], 2010) which describes a specific RBI methodology for the upstream offshore topside sector. VGB (2012) [14] has published the document S-506, which includes a procedure for RBI of components of steam boiler installations and water /steam high pressure pipes.

A further development of RBI took place in Europe with the RIMAP European research project (2001-2004) [12] which included maintenance, in addition to in-service inspection, and extended the methodology to other industries: power, steel, offshore, petrochemical and chemical industries. An outcome of this work was the publication of CWA 15740:2008 [6]. The requirements of this agreement can be achieved easily but it does not have the status of a European Norm. A follow-up to this is the RBIF-EN (2012) [11] RBI standardisation project initiated in 2012 and run by Working Group (WG) 12, under the CEN Technical Committee (TC) 319 dedicated to maintenance. The main objective of RBIF-EN project is to support the development of a European Standard (EN) for RBI during the in-service activities which are still not harmonised throughout the European Union.

On the other hand the best known document which established the RBI methodology worldwide is API RP 581. The 1st edition of the document API 581 (2000) [4] described the basis of a specific quantitative

RBI methodology with full details: data tables, algorithms, equations, models. The second edition of API 581 (2008) [3] included significant additions in a number of areas such as pressure relief devices (PRD), heat exchanger tube bundles, aboveground storage tanks (AST) and Level-2 consequence calculations. The 3rd edition of API RP 581 (2016) [2] has just been published and it will be one of the main topics of this paper. The API 581 methodology focuses on RBI for the downstream sector, especially refineries but it can be applied to similar process industries such as offshore Oil & Gas or thermal power plants with some extensions/ adjustments. P. Topalis et al (2015) [13] report a case study of application of API RP 581 3rd edition to a coal-fired power plant in Malaysia. The basic API 581 approach was found to be appropriate but it was supplemented by additional damage mechanism models, a re-thinking of the plant asset hierarchy and an adjustment of the assessment workflow.

This paper will first present some new features of the 3rd edition of API RP 581 and will then continue with a case study of application of the methodology to a gas plant in France.

API RP 581 THIRD EDITION NEW FEATURES

The single most significant new feature of the 3rd edition is the method of calculating probability of failure for the internal or external thinning damage mechanisms.

Probability of failure for thinning damage mechanisms

Loss of wall for a vessel or pipe can occur on the inside of the equipment or on the outside under insulation or in the absence of insulation. According to the API RP 581 classification, there are 3 mechanisms affected by this change:

- Internal Thinning
- External corrosion for ferritic components
- Corrosion under insulation for ferritic components

It is worth remembering the equation for calculating the probability of failure $P_f(t)$ for an equipment item and a given damage mechanism in the API 581 methodology:

$$P_f(t) = gff \cdot F_{MS} \cdot D_f(t)$$

Where gff is the generic failure frequency
F_{MS} is the management systems factor
$D_f(t)$ is the damage factor

As the original intention of API 581 was to provide a workbook for easy hand calculations, the damage factor was initially tabulated for a small number of parameters, particularly the A_{rt} parameter, which is the ratio of wall loss over the initial thickness.

Figure 2 shows the table that was included in the 1st and 2nd edition of API RP 581 for the calculation of the thinning damage factor. This was based on a structural reliability model, which uses a limit state function g = Load – Resistance, supplemented by a Bayesian approach to account for the equipment inspection history. “Smoothened” values had actually been used in the table to avoid some imperfections of the model but the process of producing the A_{rt} table was not very transparent.

A_{rt}	Inspection Effectiveness												
	E	1 Inspection				2 Inspections				3 Inspections			
		D	C	B	A	D	C	B	A	D	C	B	A
0.02	1	1	1	1	1	1	1	1	1	1	1	1	1
0.04	1	1	1	1	1	1	1	1	1	1	1	1	1
0.06	1	1	1	1	1	1	1	1	1	1	1	1	1
0.08	1	1	1	1	1	1	1	1	1	1	1	1	1
0.10	2	2	1	1	1	1	1	1	1	1	1	1	1
0.12	6	5	3	2	1	4	2	1	1	3	1	1	1
0.14	20	17	10	6	1	13	6	1	1	10	3	1	1
0.16	90	70	50	20	3	50	20	4	1	40	10	1	1
0.18	250	200	130	70	7	170	70	10	1	130	35	3	1
0.20	400	300	210	110	15	290	120	20	1	260	60	5	1
0.25	520	450	290	150	20	350	170	30	2	240	80	6	1
0.30	650	550	400	200	30	400	200	40	4	320	110	9	2
0.35	750	650	550	300	80	600	300	80	10	540	150	20	5
0.40	900	800	700	400	130	700	400	120	30	600	200	50	10
0.45	1050	900	810	500	200	800	500	160	40	700	270	60	20
0.50	1200	1100	970	600	270	1000	600	200	60	900	360	80	40
0.55	1350	1200	1130	700	350	1100	750	300	100	1000	500	130	90
0.60	1500	1400	1250	850	500	1300	900	400	230	1200	620	250	210
0.65	1900	1700	1400	1000	700	1600	1105	670	530	1300	880	550	500

Figure 2: Thinning damage factor as function of Art in the 1st and 2nd edition of API RP 581

The perception in the industry was that the old A_{rt} table had a number of weaknesses:

- The table only considered Art and the past inspection history as input parameters, while other parameters had been set to average values but these average values didn't represent well all situations.
- The table was not applicable to spherical/ semi-spherical equipment
- The process of producing the table values, including the smoothening of the model values was not documented and was difficult to defend.
- The A_{rt} approach didn't reference the design minimum thickness and this created a clash between the RBI results and the minimum thickness analysis.
- The original A_{rt} approach was based on a generalised thinning failure mode and it was not clear how this could be applied to localised thinning.

Because of these perceived weakness the thinning factor calculation method was revised and the A_{rt} tables were replaced with a more rigorous calculation procedure, as shown in Figure 3, which makes use of strength ratios SR_p and design minimum thickness. This procedure is now used for internal thinning (except tank bottoms), external corrosion and corrosion under insulation for ferritic components. A_{rt} tables are still used for tank bottoms and for SCC damage factors.

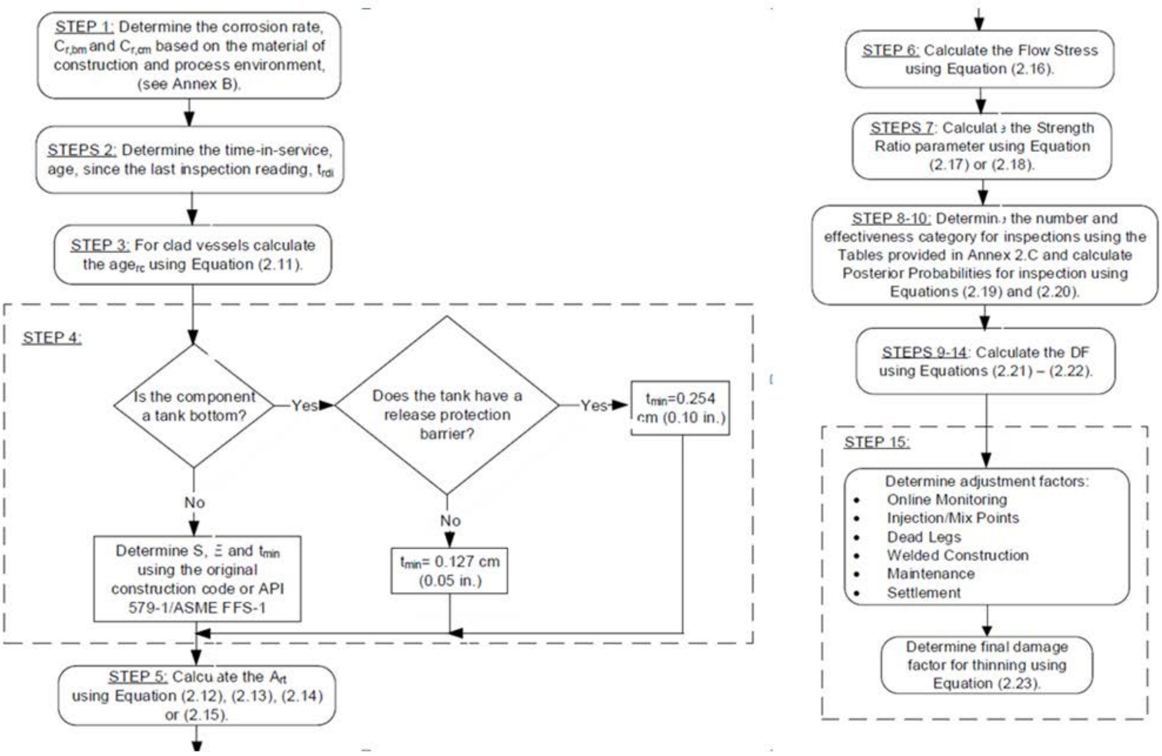


Figure 3: Thinning damage factor calculation procedure in API RP 581 3rd edition

Other changes

The HTHA (High Temperature Hydrogen Attack) quantitative RBI model described in previous 1st and 2nd editions of API 581 was based on previous versions of the API 941 and has been subject to criticism after recent accident in the refining industry. The accident investigation indicated that the old Nelson curves for carbon steel were not conservative enough. During preparation of the 3rd edition of API 581, API 941 was still under revision and there was no sufficient time for preparation of an update of the quantitative RBI method for HTHA in API RP 581.

Therefore API 581 3rd edition describes a conservative screening approach for HTHA while it is left to the owner / operator to take the responsibility and put more details into the HTHA RBI approach. The latest edition of API 941 came out in February 2016 with updated HTHA carbon steel curves but this new information has not yet been included in API 581.

There is a new appendix in API 581 with updated inspection effectiveness tables: tables of the various inspection techniques (including coverage) and their effectiveness for each damage mechanism. New tables now appear for heat exchanger tube bundle inspections.

Smaller updates also appear in numerous other parts of the standard such as in the risk matrix definition, generic failure frequencies, the PRD model, the calculation of alkaline sour water corrosion rates etc.

RISK BASED INSPECTION IMPLEMENTATION

This paper describes the implementation of API RP 581 RBI 3rd edition approach in the Synergi Plant RBI Onshore software (DNV GL, 2016). In practice the RBI implementation is part of the integrity management of the plant. Figure 4 shows a typical integrity management cycle for a plant based on the Plan-Do-Check-Act (PDCA) approach and this is basically the cycle facilitated by the Synergi Plant software. Based on equipment data and past inspection history, risk for each item is evaluated, including consequence of failure and likelihood of failure. This allows elaboration of an effective inspection program, including inspection methods, timing and coverage.

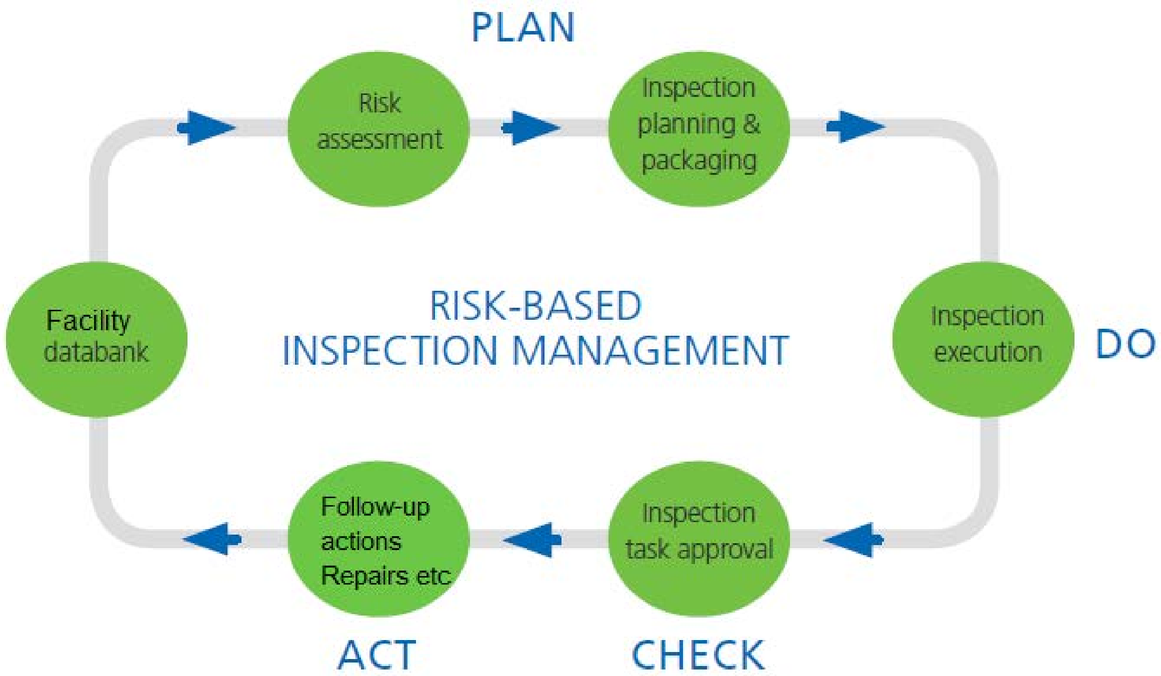


Figure 4: Plan-Do-Check-Act (PDCA) Cycle in Integrity Management

In turn, this is translated into a detailed inspection plan, which is executed and the results are evaluated with the possibility of follow-up actions. The new inspection data are fed back into the next cycle of risk assessment and inspection planning. The risk assessment circle in Figure 4 is what is typically understood as RBI.

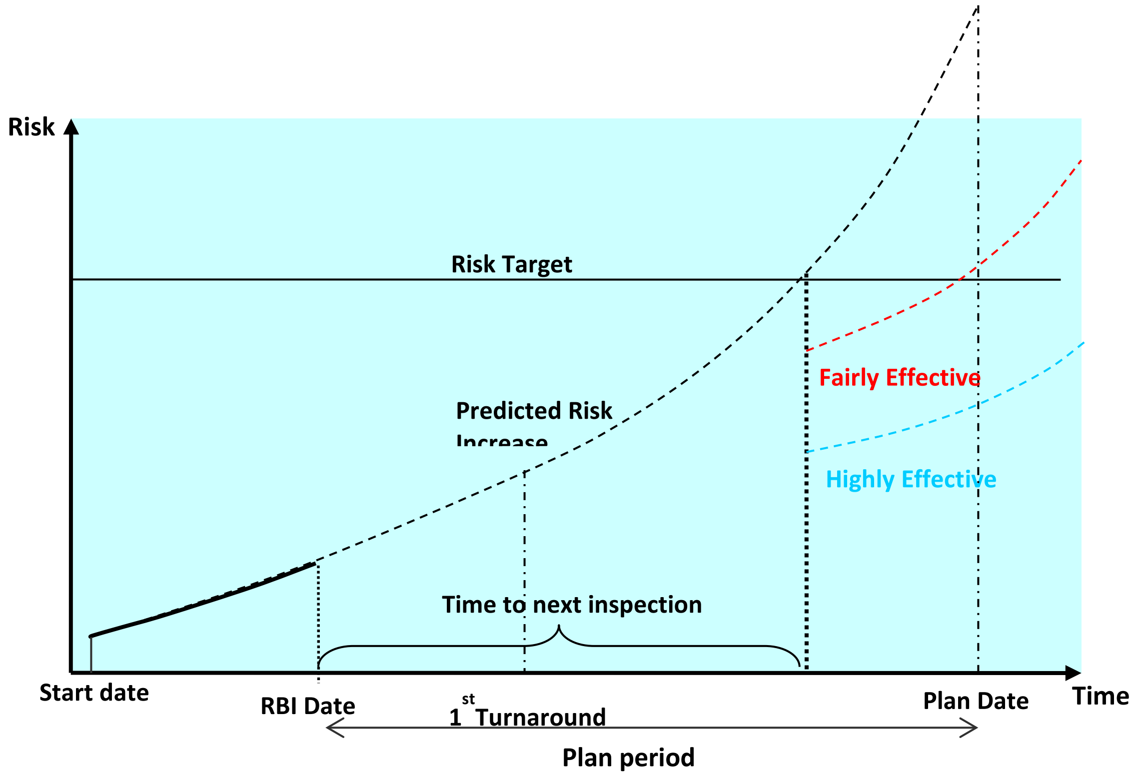


Figure 5: Inspection planning based on quantitative risk criteria

Figure 5 shows the API RP 581 approach for determining inspection dates and inspection tasks / effectiveness based on the quantitative calculation of the component risk as function of time. One or more inspection targets (e.g. maximum acceptable risk) must be set and the model algorithm identifies a date when the risk intersects the target line. The method also suggests the required inspection effectiveness (typically the minimum acceptable effectiveness, which allows the risk value to be within the acceptable limits at the future evaluation date. This suggested effectiveness is then converted to a specific inspection technique and coverage based on the API 581 inspection effectiveness tables.

This approach can be used both for planning the inspection activities for the periodic turnaround / shutdown as well as for planning the on-stream inspections. Since many plant inspections are still performed during the shutdowns, this approach is typically appropriate for defining the scope of inspections for the shutdown.

CASE STUDY - RBI IMPLEMENTATION IN THE TIGF GAS PLANT IN FRANCE

RBI is well accepted in France as a method to assess pressure equipment risks and plan inspections accordingly and has been used in the Oil & Gas, chemical and petrochemical industry during the last 10 years. On the other hand the regulatory framework in France for managing in-service inspections is quite specific to the country and there are some constraints on inspection and requalification intervals which need to be respected. Overall the API RP 581 methodology is accepted in the country but it is very interesting to see a specific case study (TIGF gas plant) to understand how the methodology fits the French regulatory framework.

TIGF (Transport Infrastructures Gaz France) is France's second largest Natural Gas Transmission and Storage company with operations focused in the South West of France. This includes underground gas storage, a gas Plant and pipelines. The gas plant handles gas which comes from storage, it is slightly wet and it contains a very small fraction of H_2S. The main production unit includes several process units such as a wells, primary separation, dehydration, desulfurization, compression, odorisation, buried pipelines as well as utilities and safety systems.

The plant has been in operation for a few decades and it has a well-established recognised inspection service (Service d'Inspection Reconnue, SIR) according to the French regulations and it has implemented RBI in the past based on an older version of API 581.

Regulatory background

RBI application for pressurised equipment in the oil & gas, chemical and petrochemical industry is regulated in France typically by 2 possible guidance documents:

Guide Plan d' Inspection DT84 (DT84, 2010). Installations meeting the requirements of this guidance document can perform inspection based on RBI with maximum inspection and requalification interval of 6 years and 12 years respectively

Guide Plan d' Inspection DT32 (DT32, 2008). Installations meeting the requirements of this guidance document can perform inspection based on RBI with maximum inspection and requalification interval of 5 years and 10 years

The first document (DT 84) has stricter requirements but it allows slightly longer inspection and requalification intervals.

The TIGF gas plant of our case study meets the requirements of DT 84. To simplify for our international readers this means:

- 6-yearly shutdown, when periodic inspections (IP) are generally performed on all equipment, assuming that the RBI allows this and the maximum inspection interval is 6 years. The types of performed inspections depend on the damage mechanisms. Generally a visual inspection is performed on all equipment (as well as the attached safety and pressure accessories) and additional inspections (specific controls) may be performed depending on active damage mechanisms and RBI.
- 12-yearly requalification which coincides with the one out of two 6-yearly periodic turnarounds but it also includes a hydro-test (unless it is under regulatory exemption) and verification of documents.
- Additional inspections (or specific controls) may have to be performed between the 6-yearly shutdowns if the RBI indicates that the risk is high and more frequent inspections are required.

The fundamental requirement is that each equipment must have its own "inspection plan" ("written scheme of examination" is a more common term in English) which specifies the details (nature, periodicity, location etc.) of periodic inspections, requalification examinations or other inspections recommended by the RBI.

Inspection planning workflow for TIGF gas plant

Figure 6 shows the inspection planning workflow that has been configured in the Synergi Plant software for the TIGF gas plant so that the French regulatory requirements can be met.

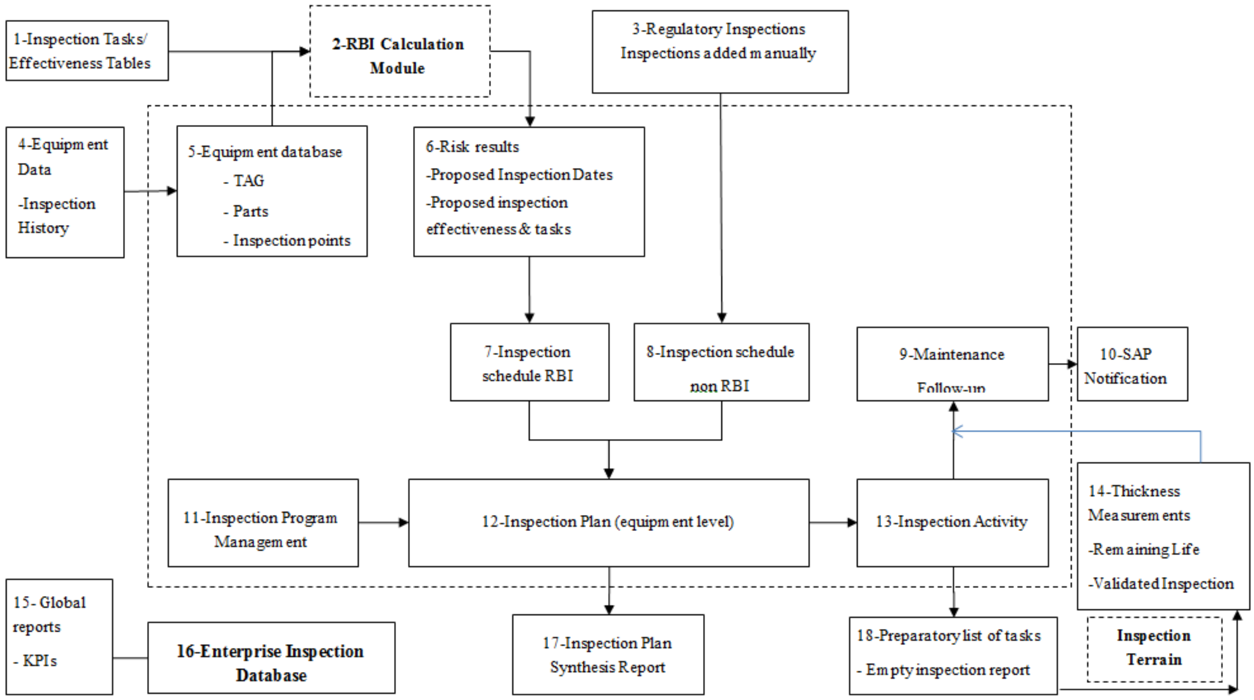


Figure 6: TIGF gas plant inspection planning flow diagram combining RBI and regulatory constraints

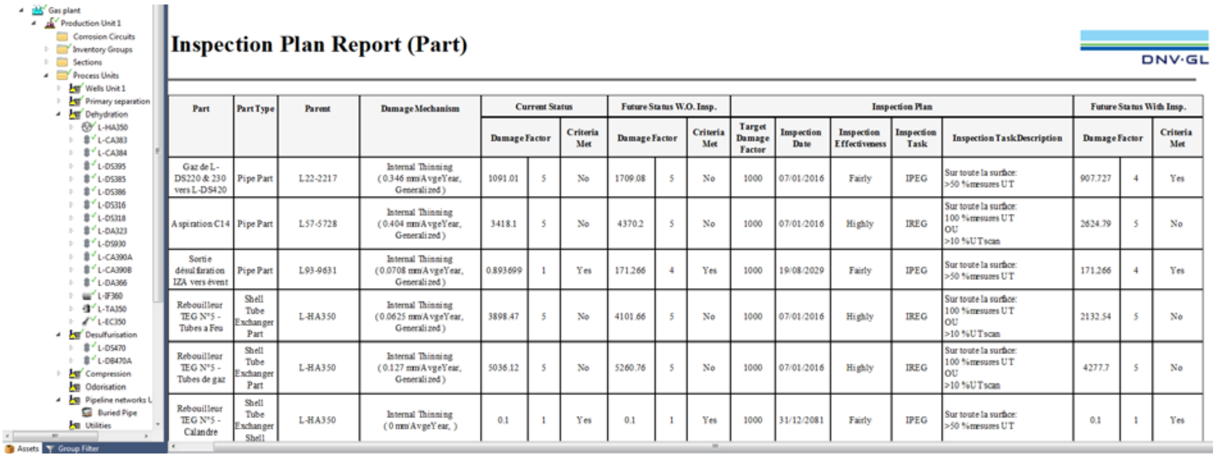
The RBI module (box 2) is fed with equipment data and inspection history data (boxes 4 and 5) as well as configuration data (e.g. fluid data, material data, inspection tasks and their effectiveness) and is run for the selected scope of equipment to calculate risk results and a generic inspection plan, including inspection dates and inspection tasks for each component (box 6). The RBI inspection results are fed into the scheduling system in the form of RBI inspection schedule (box 7). In addition to this, regulatory inspection planning requirements in the form of periodic inspections (IP) and periodic re-qualifications (RP) also feed the scheduling system in the form of non-RBI inspection schedule (box 8). Both RBI schedules and non-RBI schedules are combined into the equipment “inspection plan” (box 12). An inspection plan synthesis report (box 17) can then be produced which includes basic equipment data, equipment risk levels and planned inspections activities.

The inspection plan is reviewed and approved by the responsible person. Once the inspection plan is confirmed, the inspection activities (box 13) can be generated for the whole inspection planning period, which is typically the 12-year re-qualification cycle. For each inspection activity, a preparatory list of tasks and an empty inspection report can be generated (box 18) before execution of the inspection. Once the inspection is done, observations and thickness measurements are recorded, remaining lives are calculated and a validated inspection report is produced (box 14).

If an anomaly is found, which requires action, a follow-up maintenance activity is generated (box 9). The follow-up activity can then send a maintenance notification into the ERP system (SAP in this case) for a work order generation.

All results are stored in the enterprise inspection database for the production of Key Performance Indicators (KPIs) and display of reports and dashboards. A highly configurable utility is available for the configuration of dashboards.

Figure 7 shows an inspection summary report from the RBI module. These are suggested inspection activities before validation of the equipment inspection plan.

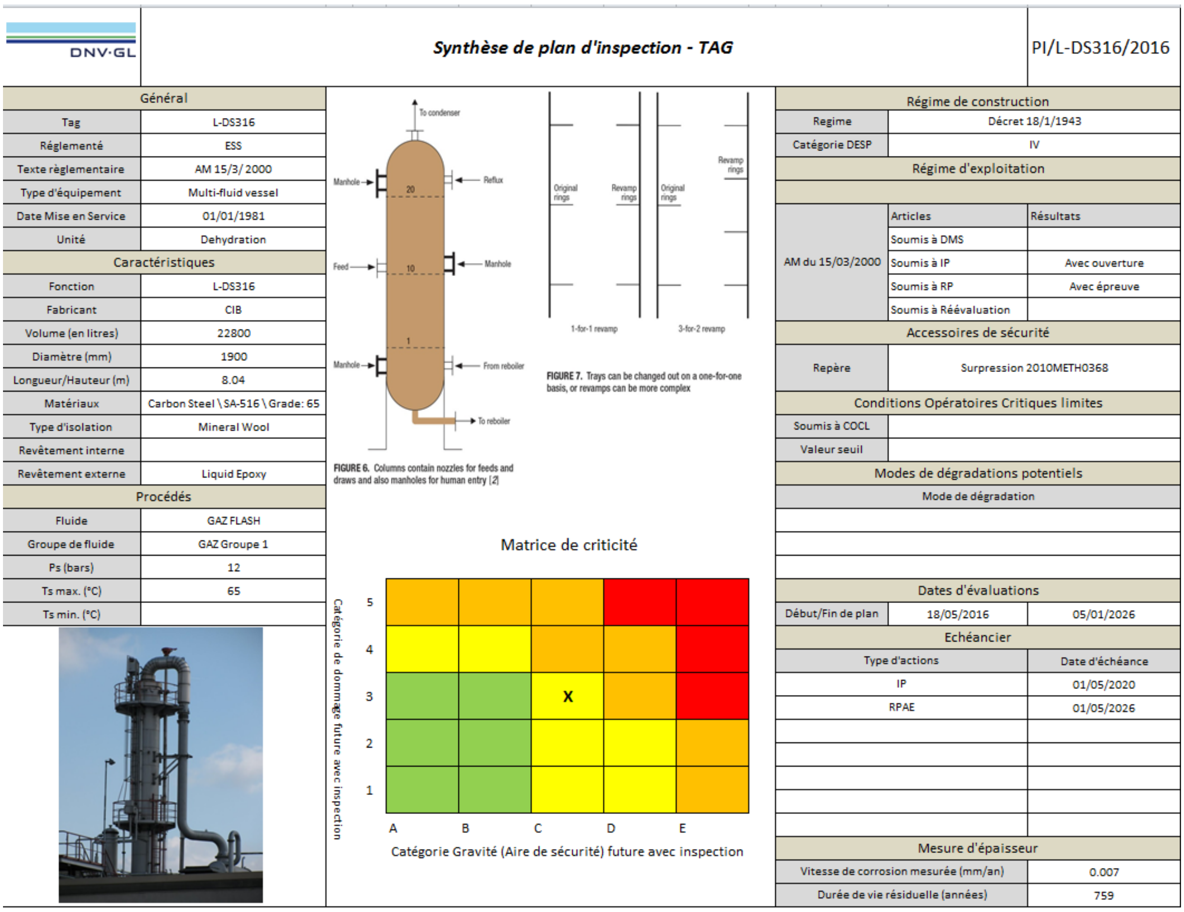


Inspection Plan Report (Part)

Part	Part Type	Parent	Damage Mechanism	Current Status			Future Status W.O. Imp.			Inspection Plan					Future Status With Imp.		
				Damage Factor		Criteria Met	Damage Factor		Criteria Met	Target Damage Factor	Inspection Date	Inspection Effectiveness	Inspection Task	Inspection Task Description	Damage Factor		Criteria Met
Gaz de L-DS220 & 230 vers L-DS420	Pipe Part	L22-2217	Internal Thinning (0.346 mm/AvgeYear, Generalized)	1091.01	5	No	1709.08	5	No	1000	07/01/2016	Fairly	IPEG	Sur toute la surface: >50 %mesures UT	907.727	4	Yes
Aspiration C14	Pipe Part	L57-5728	Internal Thinning (0.404 mm/AvgeYear, Generalized)	3418.1	5	No	4370.2	5	No	1000	07/01/2016	Highly	IREG	Sur toute la surface: 100 %mesures UT OU >10 %UT scan	2624.79	5	No
Sortie désulfuration IZA vers évent	Pipe Part	L93-9631	Internal Thinning (0.0708 mm/AvgeYear, Generalized)	0.893699	1	Yes	171.266	4	Yes	1000	19/08/2029	Fairly	IPEG	Sur toute la surface: >50 %mesures UT	171.266	4	Yes
Rebouilleur TEG N°5 - Tubes a Feu	Shell Tube Exchanger Part	L-HA350	Internal Thinning (0.0625 mm/AvgeYear, Generalized)	3898.47	5	No	4101.66	5	No	1000	07/01/2016	Highly	IREG	Sur toute la surface: 100 %mesures UT OU >10 %UT scan	2132.54	5	No
Rebouilleur TEG N°5 - Tubes de gaz	Shell Tube Exchanger Part	L-HA350	Internal Thinning (0.127 mm/AvgeYear, Generalized)	5036.12	5	No	5260.76	5	No	1000	07/01/2016	Highly	IREG	Sur toute la surface: 100 %mesures UT OU >10 %UT scan	4277.7	5	No
Rebouilleur TEG N°5 - Calandre	Shell Tube Exchanger Shell	L-HA350	Internal Thinning (0 mm/AvgeYear,)	0.1	1	Yes	0.1	1	Yes	1000	31/12/2081	Fairly	IPEG	Sur toute la surface: >50 %mesures UT	0.1	1	Yes

Figure 7: Inspection summary report from RBI

Figure 8 shows a sample inspection plan synthesis report for one equipment, which is used for validation of the equipment inspection plan.



Synthèse de plan d'inspection - TAG — PI/L-DS316/2016

Général	
Tag	L-DS316
Réglementé	ESS
Texte règlementaire	AM 15/3/2000
Type d'équipement	Multi-fluid vessel
Date Mise en Service	01/01/1981
Unité	Dehydration
Caractéristiques	
Fonction	L-DS316
Fabricant	CIB
Volume (en litres)	22800
Diamètre (mm)	1900
Longueur/Hauteur (m)	8.04
Matériaux	Carbon Steel \ SA-516 \ Grade: 65
Type d'isolation	Mineral Wool
Revêtement interne	
Revêtement externe	Liquid Epoxy
Procédés	
Fluide	GAZ FLASH
Groupe de fluide	GAZ Groupe 1
Ps (bars)	12
Ts max. (°C)	65
Ts min. (°C)	

Régime de construction		
Regime	Décret 18/1/1943	
Catégorie DESP	IV	
Régime d'exploitation		
	Articles	Résultats
AM du 15/03/2000	Soumis à DMS	
	Soumis à IP	Avec ouverture
	Soumis à RP	Avec épreuve
	Soumis à Réévaluation	
Accessoires de sécurité		
Repère	Surpression 2010METH0368	
Conditions Opératoires Critiques limites		
Soumis à COCL		
Valeur seuil		
Modes de dégradations potentiels		
Mode de dégradation		
Dates d'évaluations		
Début/Fin de plan	18/05/2016	05/01/2026
Echéancier		
Type d'actions		Date d'échéance
IP		01/05/2020
RPAE		01/05/2026
Mesure d'épaisseur		
Vitesse de corrosion mesurée (mm/an)		0.007
Durée de vie résiduelle (années)		759

Figure 8: Sample of Inspection Plan Synthesis Report

CONCLUSION

The 3rd edition of API RP 581 RBI methodology has recently been published (April 2016) and contains some significant improvements especially in the calculation of damage factors for internal thinning, external corrosion and corrosion under insulation. These improvements have already been implemented in the latest version of the DNV GL Synergi Plant software, which integrates risk calculations with the more detailed inspection planning, inspection reporting and integrity management functionality. Implementation of the latest API RP 581 methodology is described for the TIGF gas plant in France operating under the requirements of "Guide Plan d' Inspection DT84 (2010)". The new API 581 methodology proves to be suitable and compatible with the current French regulations. Appropriate software configuration allows a quantitative RBI approach which respects the regulatory periodic inspection and requalification intervals.

ABBREVIATIONS

API American Petroleum Institute

Art (Age * CorrosionRate) / Thickness

AST Aboveground Storage Tanks

CEN Comité Européenne de Normalisation

CMMS Computerized Maintenance Management Systems

CoF Consequence of failure

CWA CEN Workshop Agreement

D_f Damage factor

DNV GL Company created from the merger of Det Norske Veritas (DNV) and Germanischer Lloyd (GL)

EN European Norm

ERP Enterprise Resource Planning

F_{MS} Management Systems Factor

gff Generic Failure Frequency

HTHA High Temperature Hydrogen Attack

IP Inspection Periodique

KPI Key Performance Indicator

PDCA Plan-Do-Check-Act

PLL Potential Loss of Life

P_f Probability of Failure

PoF Probability of Failure

PRD Pressure Relief Devices

RBI Risk Based Inspection

RBIF Risk Based Inspection Framework

RIMAP Risk-Based Inspection And Maintenance For European Industries

RP Recommended Practice

RP Requalification Périodique

SCC Stress Corrosion Cracking

SIR Service d'Inspection Reconnue

TC Technical Committee

VGB Verband der Großkessel-Besitzer

WG Working Group

REFERENCES

[1] API RP 580, 2016. Risk-Based Inspection. API Recommended Practice 580, 3rd Edition, February 2016.

[2] API RP 581, 2016. Risk-based Inspection Methodology. API Recommended Practice 581. 3rd Edition, April 2016.

[3] API RP 581, 2008. Risk-Based Inspection Technology. API Recommended Practice 581, 2nd Edition, September 2008.

[4] API Publication 581, 2000. Risk-Based Inspection Base Resource Document 1st edition, September 2000.

[5] ASME PCC-3 2007. Inspection Planning Using Risk-Based Methods. Re-affirmed 2012.

[6] CWA 15740, 2008. European Committee For Standardisation, - Workshop Agreement on Risk-Based Inspection and Maintenance Procedures For European Industry (RIMAP).

[7] DNV GL, 2016. Synergi Plant RBI Onshore User Manual.

[8] DNV RP-G101. 2010. Recommended Practice DNV-RP-G101, Risk Based Inspection Of Offshore Topsides Static Mechanical Equipment, October 2010.

[9] DT32 Guide Plan d' Inspection , 2008. Guide Pour l'etablissement des plans d'inspection (Périodicités IP et RP 5 et 10 Ans). Union des Industries Chimiques (UIC), Union Française des Industries Pétrolières (UFIP), 2008.

[10] DT84 Guide Plan d' Inspection , 2010. Guide pour l'etablissement d'un plan d'inspection

permettant de définir la nature et les périodicités d'inspections périodiques et de requalifications pouvant être supérieures à cinq et dix ans. Union des Industries Chimiques (UIC), Union Française des Industries Pétrolières (UFIP), Comité Technique National

de l'inspection dans l'industrie Chimique (CTNIIC), Février 2010.

[11] RBIF-EN, 2012. Risk Based Inspection Framework. http://rbi.risk-technologies.com/

[12] Kauer R, Jovanovic A, Angelsen S and Vaage G, 2004. Plant Asset Management - RIMAP (Risk-Based Inspection And Maintenance For European Industries)- The European Approach. ASME PVP-Vol. 488, Risk and Reliability and Evaluation of Components and Machinery. July 25-29, 2004, San Diego, California, US.

[13] Topalis P., Wong S.L., Md Sidek A.S, Jaske C., 2015. Risk Based Inspection for a Thermal Power Plant in Malaysia – Case Study, Methodology and Software. 41st MPA-Seminar, October 5th and 6th 2015, Stuttgart.

[14] VGB, 2012 - S-506, Guideline Condition Monitoring and Inspection of Components Of Steam Boiler Installations And Water Or Steam Bearing High Pressure Pipes, Germany.

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