RISK-BASED INSPECTION METHODOLOGY

API Recommended Practice 580/581

EPERC Seminar Rome, April 1st to 3rd of 2019

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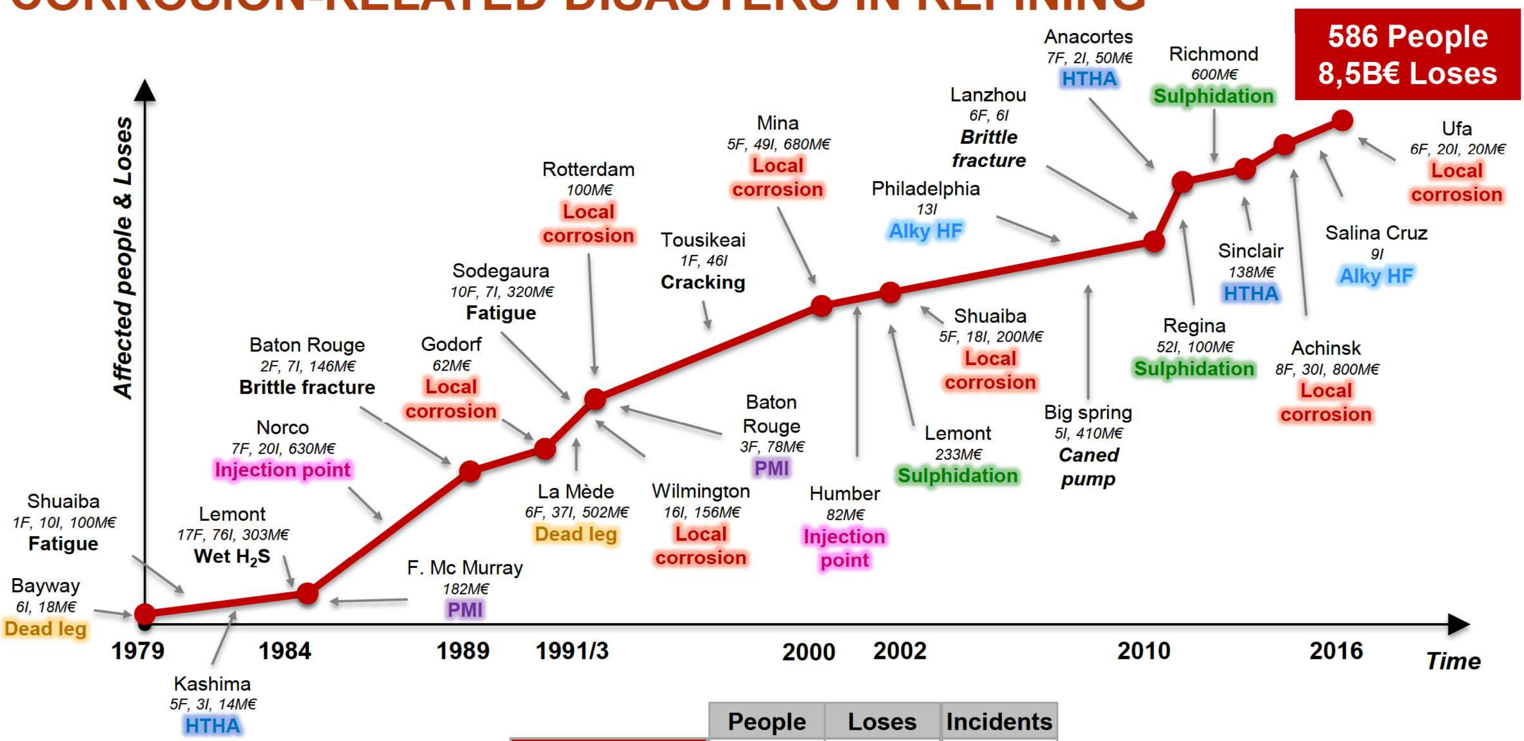
CORROSION-RELATED DISASTERS IN REFINING

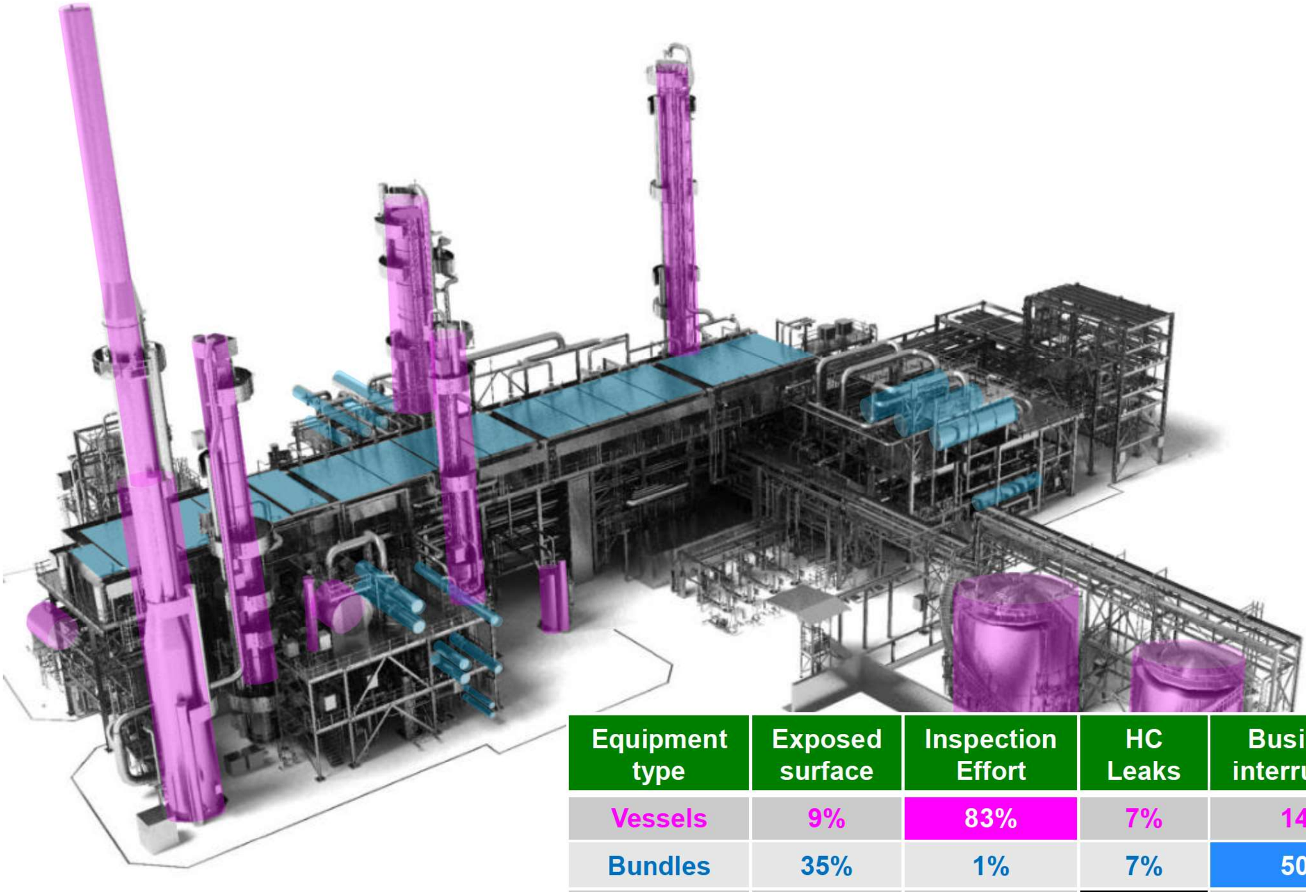


	People	Loses	Incidents
Local corrosion	143	2970	14
Sulphidation	56	1023	6
Dead leg	52	525	3
Injection point	34	714	4
Alky HF	26	59	5
HTHA	18	291	5
PMI	3	307	4

THE DIFFERENT INSPECTION APPROACHES

	Approach based on...			Risk based
	Reactive inspection	Calendar	Condition	
Strategy	**Run to Failure**	Focus on regulations	**Equipment life**	**Risk** management
Scope	Critical equipment	**Everything... you are aware!**	Unit cycle limiting equipment	Whatever is needed to operate at **acceptable risk**
Benefits	Reduced budget	Levelled scope	Run length assurance	Reduced **risk & scope**, improved **availability**
Issues	**Costly failures,** uncertainty	Increased budget, **costly failures**	**Costly decisions**	**Cultural change**

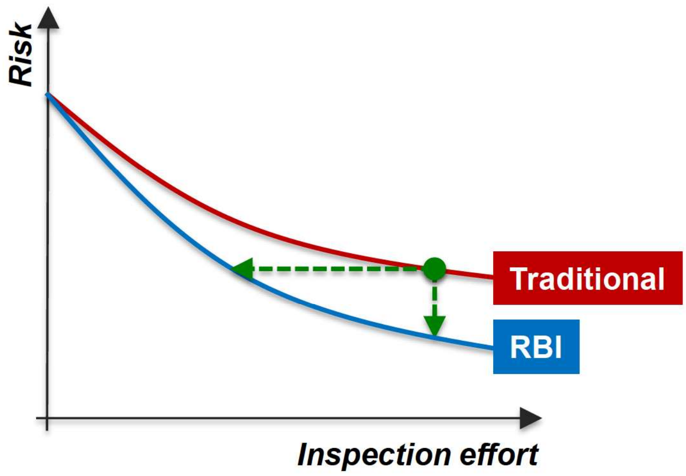
REFINING INSPECTION BACKGROUND



Equipment type	Exposed surface	Inspection Effort	HC Leaks	Business interruption
Vessels	9%	83%	7%	14%
Bundles	35%	1%	7%	50%
Piping	56%	16%	78%	32%

API RISK-BASED INSPECTION (API RBI)

- This methodology may be used to **manage the overall risk of a plant** by focusing inspection effort on the high risk equipment
- It provides the basis for **making informed decisions** on inspection scope, frequency, and the suitable NDT
- In most processing plants, a large percent of the total unit **risk will be concentrated in a relatively small percent** of equipment items
- These potential **high-risk** components may require **greater attention**, through a revised inspection plan
- The cost of increased inspection effort may be **offset by reducing excessive inspections** in the areas having lower risk



NDT: *Non destructive testing*

API RBI HISTORY & DOCUMENTS

- **1992** Joint Industry Project
- **2000** 581 1st Edition
- **2002** 580 1st Edition
- **2008** 581 2nd Edition
- **2009** 580 2nd Edition
- **2016** 580 & 581 V3

- Document 580 introduced the principles and present **minimum general guidelines for RBI**
- Document 581 provides **quantitative RBI methods** for inspection planning

DOCUMENT 580

- Content
  - What is RBI and its key elements
  - How to implement and sustain it
- Purpose: *Using RBI as* ***continuous improvement tool***
  - Refresh view when changes occur
  - Identify other risk mitigation opportunities
  - Promotes deployment of new technology
- Scope: *Target audience*
  - Primarily inspection
  - Requiring **involvement from Engineering Maintenance and Operations**
- Reassessment: *Reasons and when to conduct*
  - Damage progression & inspections
  - Effect of **mitigation strategies**
  - Following process or physical changes
  - After Maintenance Turnarounds

DOCUMENT 581

- Provides quantitative procedures to establish an inspection program using RBI methods for pressurized fixed equipment
- Risk calculation
  - Determination of probability combined with consequence of a failure (POF, COF)
  - Failure: loss of containment from pressure boundary
  - Risk increases as damage accumulates during in-service operation
  - As risk tolerance is approached, sufficient inspection effectiveness is required to quantify damage state
- Risk management
  - On-site risk to employees
  - Off-site risk to the community
  - Business interruption risks
  - Risk of damage to the environment

Document organization

Part 1: Inspection Planning

Part 2: Determination of probability of failure

Part 3: Consequence modeling

***POF**: Probability of failure, **COF:** Consequence of failure*

RISK ANALYSIS

- In general, risk is calculated as function of time as follows

$$R(t) = POF(t) \cdot C(t)$$

- The probability of failure is a function of time, since damage due to cracking, thinning or other damage mechanism increases with time
- In API RBI, the consequence of failure is assumed to be independent of time, therefore

$$R(t) = POF(t) \cdot CA \qquad \textit{for Area–based Risk}$$

$$R(t) = POF(t) \cdot FC \qquad \textit{for Financial–based Risk}$$

POF: *Probability of Failure*

TARGETS

- Defined as the maximum level acceptable for continued operation to trigger an inspection or other mitigation such as:
  - **Risk target**: A level of acceptable risk (e.g. an area of 3,25 m^2/yr.)
  - **POF Target:** A frequency of failure or leak per year that is considered unacceptable (e.g. 3,06E04)
  - **Damage Factor (DF) Target:** A damage state that reflects an unacceptable failure frequency factor greater than the generic (e.g. 1000)
  - **COF Target:** A level of unacceptable consequence in terms of Area or Financial(*)
  - **Thickness Target:** A specific thickness (e.g. minimum required thickness T_{min})
  - **Maximum interval Target:** Specific inspection frequency considered unacceptable (e.g. 15 yrs.)

(*) As COF can't be reduced though inspection, mitigation should be reducing inventory or ignition

PROBABILITY OF FAILURE (1/4)

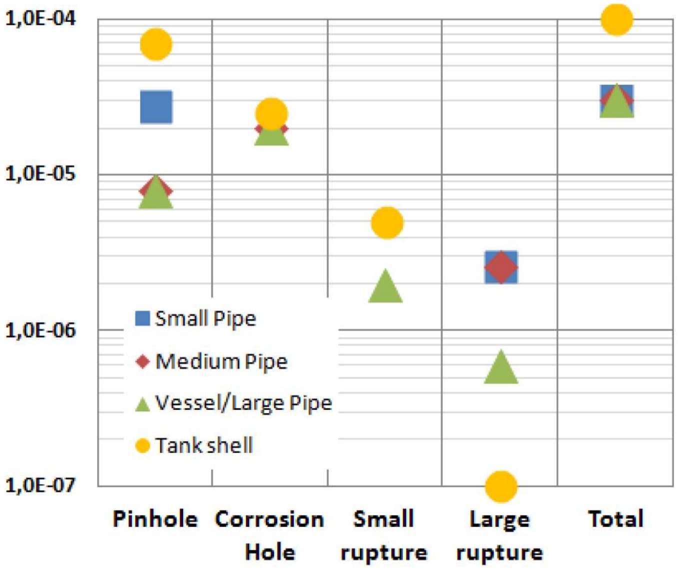
- The probability of failure in API RBI is determined by three parameters:
  - *Generic failure frequency*
  - *Damage factor*
  - *Management system factor*

$$POF(t) = gff \, . \, D_f \, . \, F_{MS}$$

Based on industry data

- ✓ *Due to fabrication flaws*
- ✓ *Non-service related damage*
- ✓ *Prior to operating exposure*

Generic failure frequency

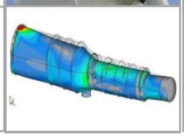


TOTAL

PROBABILITY OF FAILURE (2/4)

- The damage factor is the amount of damage as a function of time and the effectiveness of inspection

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

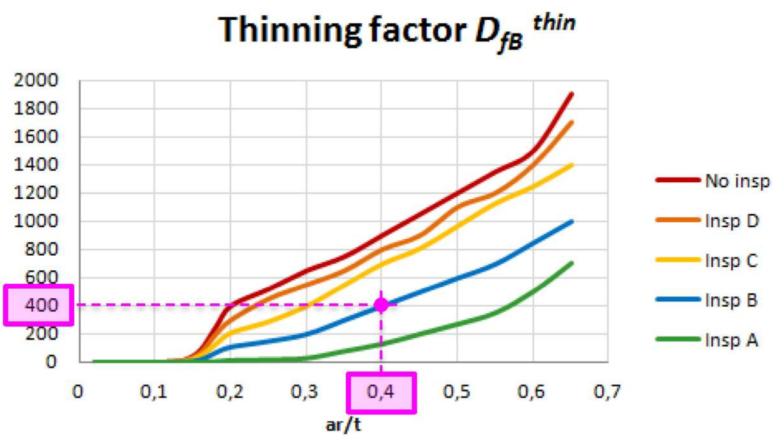
D_f^{thin}		***Internal corrosion***
D_f^{elin}		***Lining damage***
D_f^{extd}		***External corrosion***
D_f^{scc}		***Stress corrosion cracking***
D_f^{htha}		***High temperature H_2 Attack***
D_f^{brit}		***Brittle fracture***
D_f^{mfat}		***Mechanical fatigue***

$$D_{f\text{-total}} = \min [D_f^{thin}, D_f^{elin}] + D_f^{extd} + D_f^{scc} + D_f^{htha} + D_f^{brit} + D_f^{mfat}$$

PROBABILITY OF FAILURE (3/4)

- Example of internal corrosion(*). Main parameter is aging factor ar/t
  - *a: Time (e.g. 20 yrs.)*
  - *r: Corrosion rate (e.g. 0,21 mm/yr.)*
  - *t: Thickness (e.g. 10,5 mm)*

ar/t = 20 . 0,21 / 10,5 = 0,4



Using formula of API 581 V2

For 20 years & 1 Inspection B in the history

$D_f^{thin} = D_{fB}^{thin}(400) / F_{OM(**)}(10) = \mathbf{40}$

(*) Using API 581 V2 model (V3 introduces a more complex model for thinning), (**) Monitoring of main process variables

PROBABILITY OF FAILURE (4/4)

- Based on the result of an Audit protocol, it accounts for the influence of the facility's management system in place (PSM, MOC, Mechanical integrity, etc.)
- Assumes that the chance of identifying accumulated damage during inspection is proportional to the quality of PSM program

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

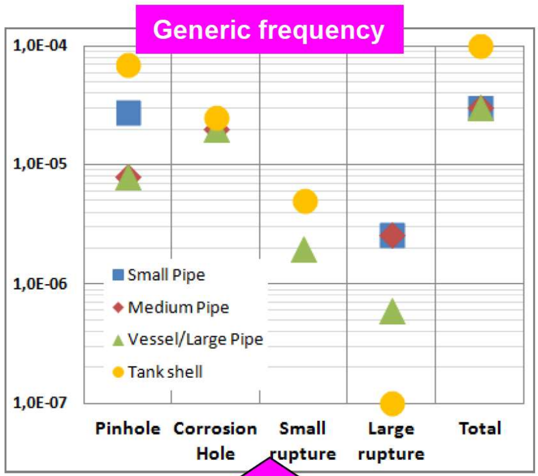
- ✓ $F_{MS} = 10^{(-0,02.Pscore+1)}$
- ✓ *Pscore as percent of the audit result*
- ✓ *Frequently set to 0,4 in the industry*

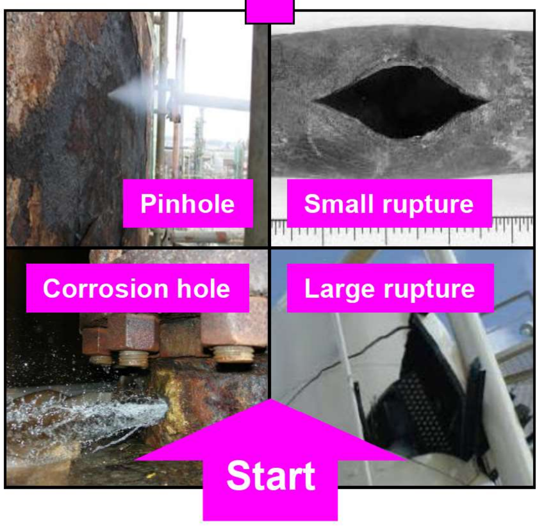
Title	Ques-tions	Points
Leadership	6	70
Process safety information	10	80
Process Hazard Analysis	9	10
MOC	6	80
Operating procedures	7	80
Safe work practices	7	85
Training	8	100
Mechanical integrity	20	120
Pre-startup safety review	5	60
Emergency response	6	65
Incident investigation	9	75
Contractors	5	45
Audits	4	40
Total	**101**	**1000**

***PSM**: Process safety Management, **MOC**: Management of Change*

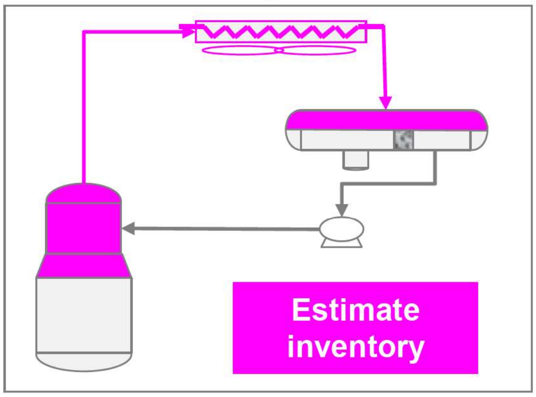
CONSEQUENCE OF FAILURE (1/4)

- Select hole sizes, Determine fluid properties, calculates release rate and estimate fluid inventory



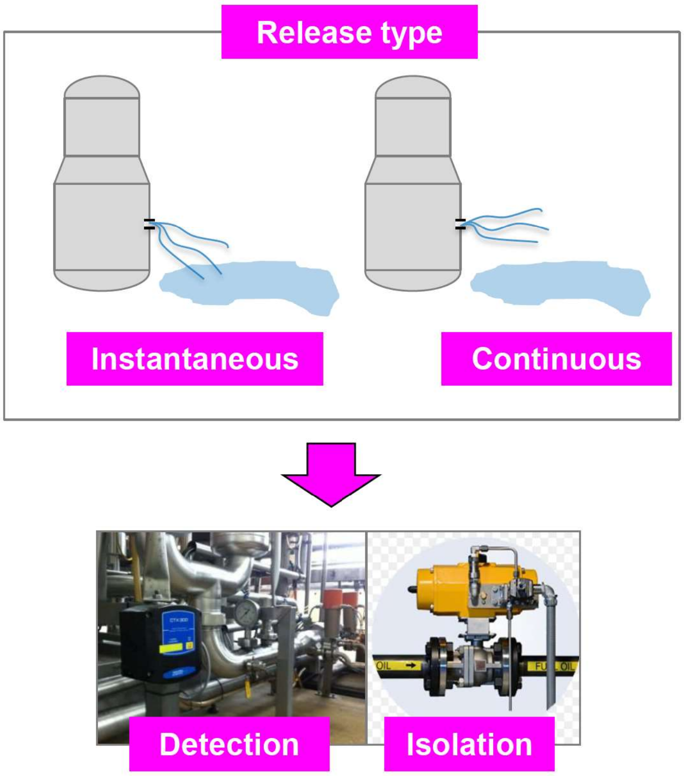


Fluid properties
Liquid release rate
Vapor release rate



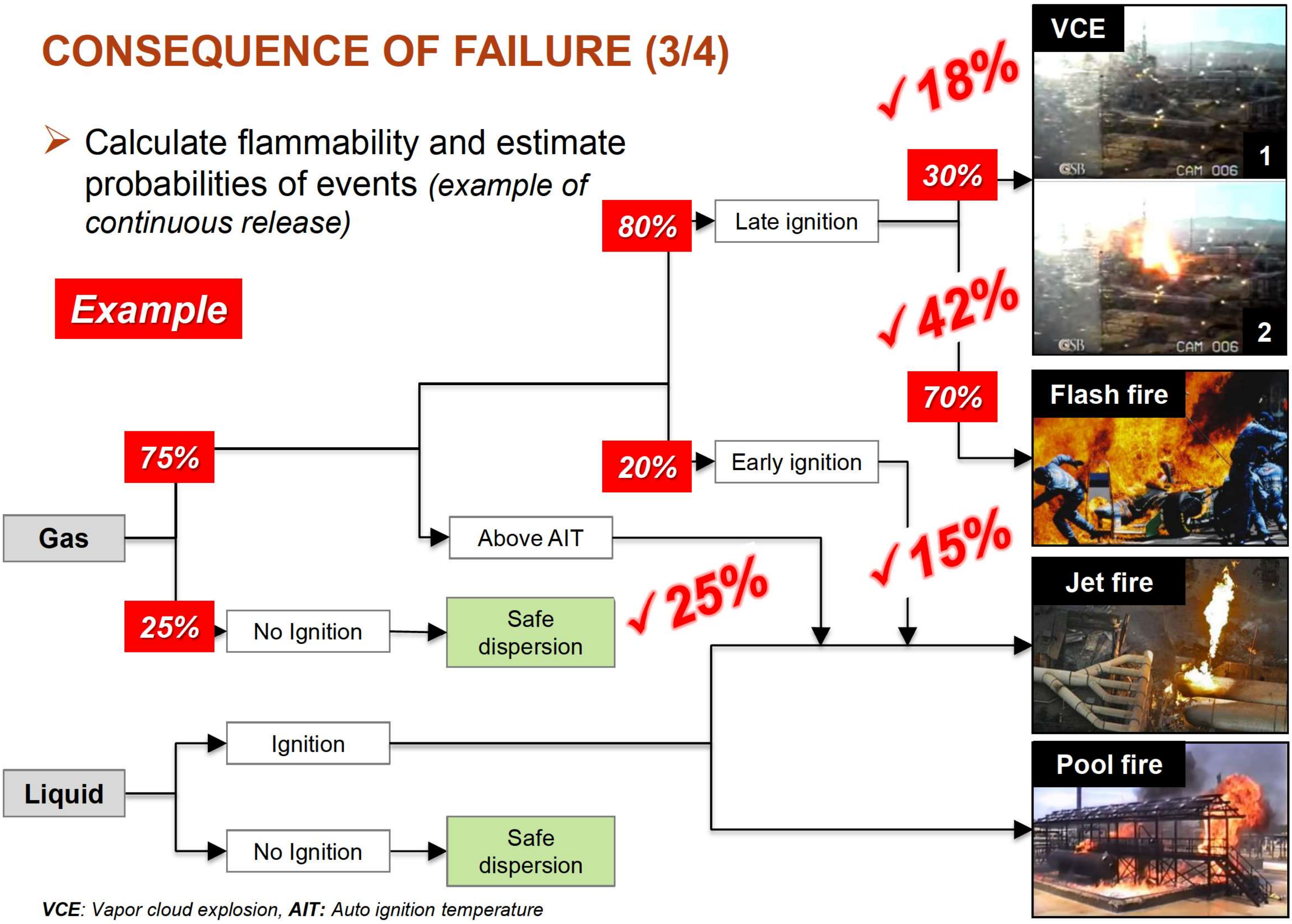
CONSEQUENCE OF FAILURE (2/4)

- Determine release type and assess detection and isolation systems



CONSEQUENCE OF FAILURE (3/4)

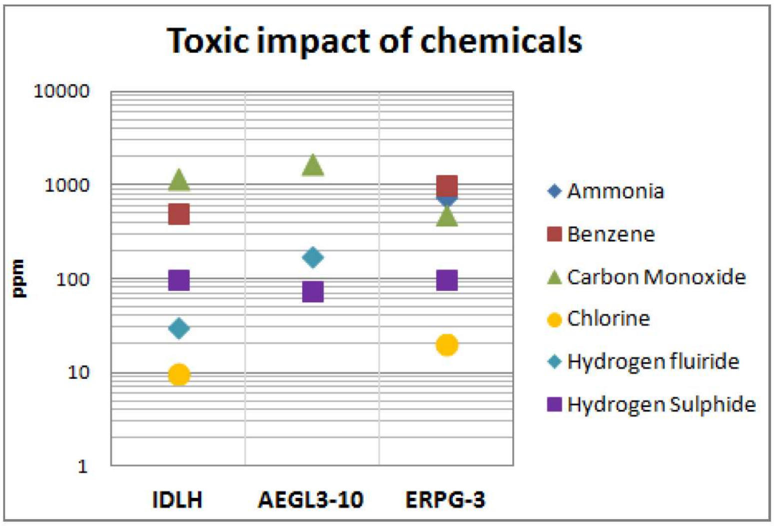
- Calculate flammability and estimate probabilities of events *(example of continuous release)*



***VCE**: Vapor cloud explosion, **AIT:** Auto ignition temperature*

CONSEQUENCE OF FAILURE (4/4)

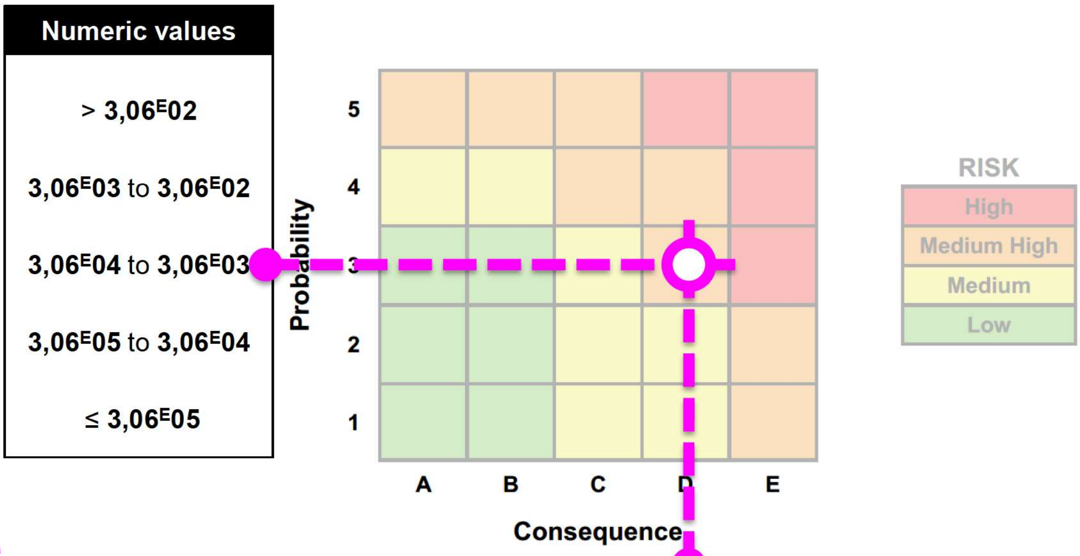
- Calculation of toxic consequence
  - *Common chemical industry toxic materials & representative fluid*
  - *Determination of toxic release and probabilities*
  - *Toxic COF for HF, H2S, Ammonia and Chlorine*
- Non-Flammable Non-Toxic consequences
  - *Steam, acid caustic leaks*
- Environmental consequence
  - *Based on remediation & clean-up cost*
- Financial consequence
  - *Cost of equipment (and surroundings) repair and replacement*
  - *Business interruption*



IDLH: *Immediately dangerous to life or health,* ***AEGL3-10***: *Acute exposure guideline Level (10 '),* ***ERPG-3***: *Emergency response planification guideline*

FINAL RISK ANALYSIS

- Once the Probability and the maximum consequence are calculated, the result can be placed into the Risk Matrix



Example

POF = 3,06E05 . 40 . 0,4 = ***4,9E04***

COF = ***2500*** *m²*

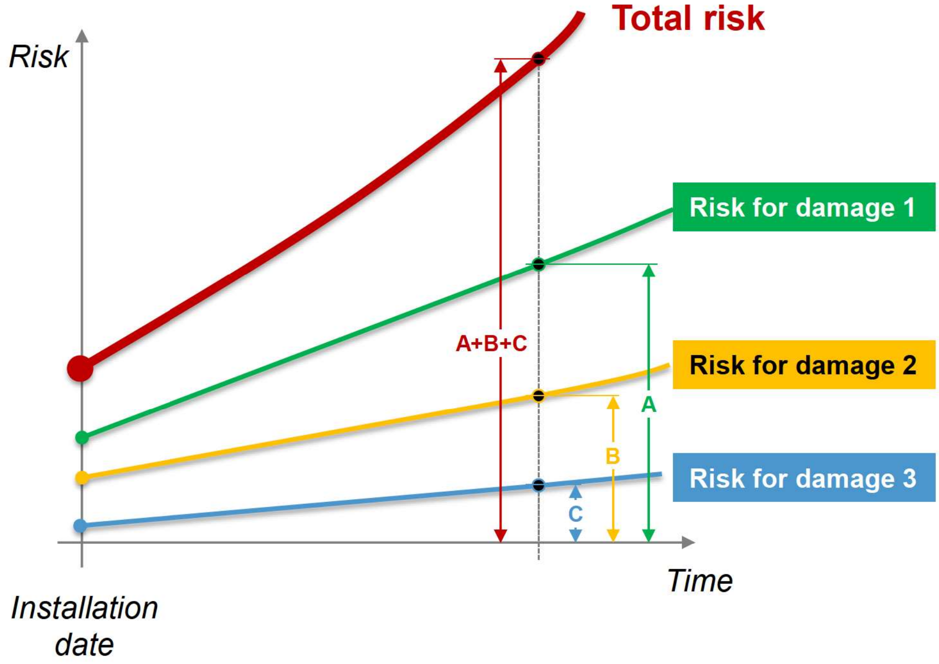
Risk: ***Medium-High***

≤ 9,29	9,29 to 92,9	92,9 to 929	929 to 9290	> 9290
Area associated value (m²)				

INSPECTION PLANNING (1/5)

- Risk increases with time as component damage increases
- If multiple damage occurs at the same time, the principle of superposition is used to derive total risk
- At some point in time, risk reaches the user's specified risk target

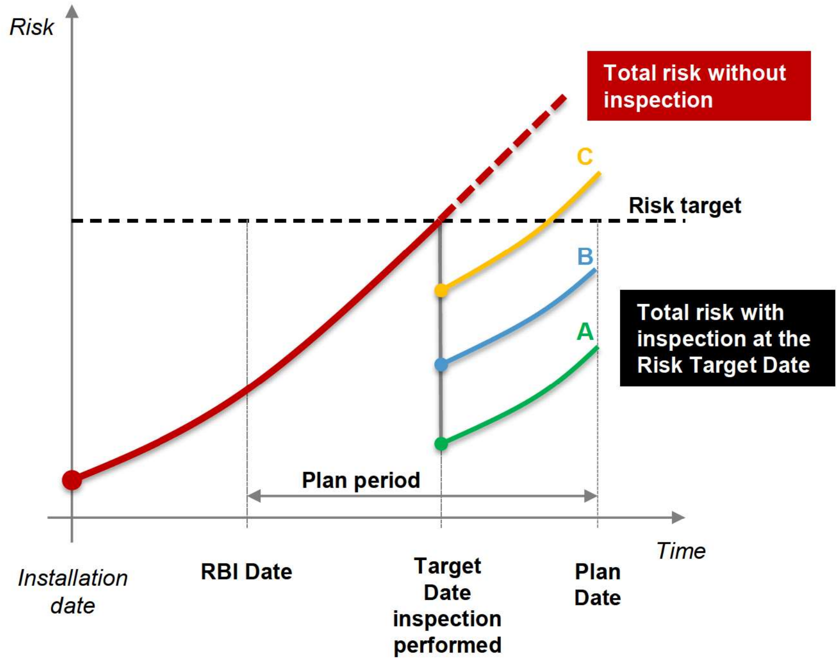
Superposition of risk



INSPECTION PLANNING (2/5)

- Inspection planning involves recommending the number and level of inspection required to reduce risk to acceptable value at plan date
- Inspection effectiveness is graded A to E with A providing the greatest certainty of finding damage and E representing no inspection

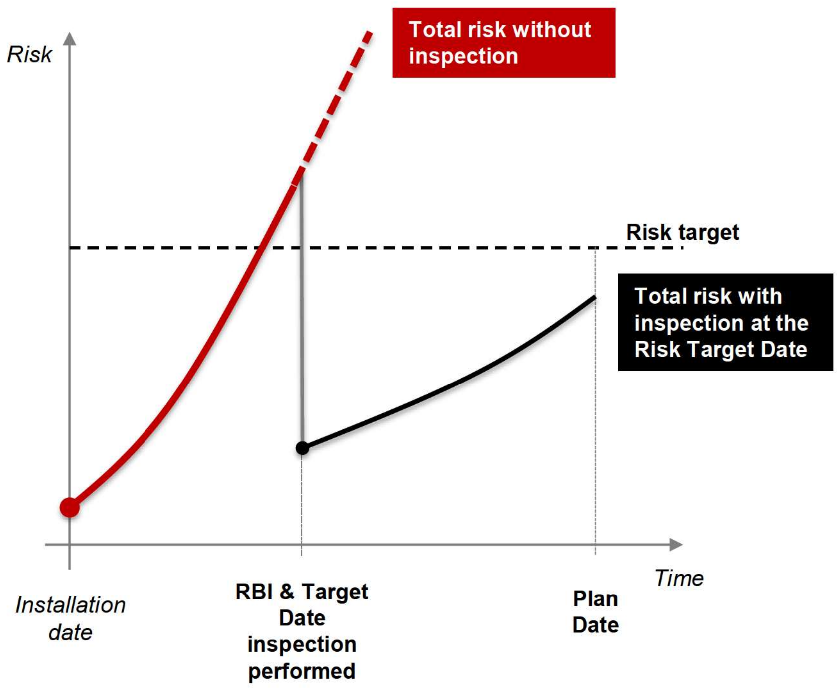
Case 1: ***Risk exceeding target between RBI Date and Plan date***



INSPECTION PLANNING (3/5)

- For many applications, the user's risk target has been exceeded at the time of the RBI analysis is performed
- Inspection is recommended immediately

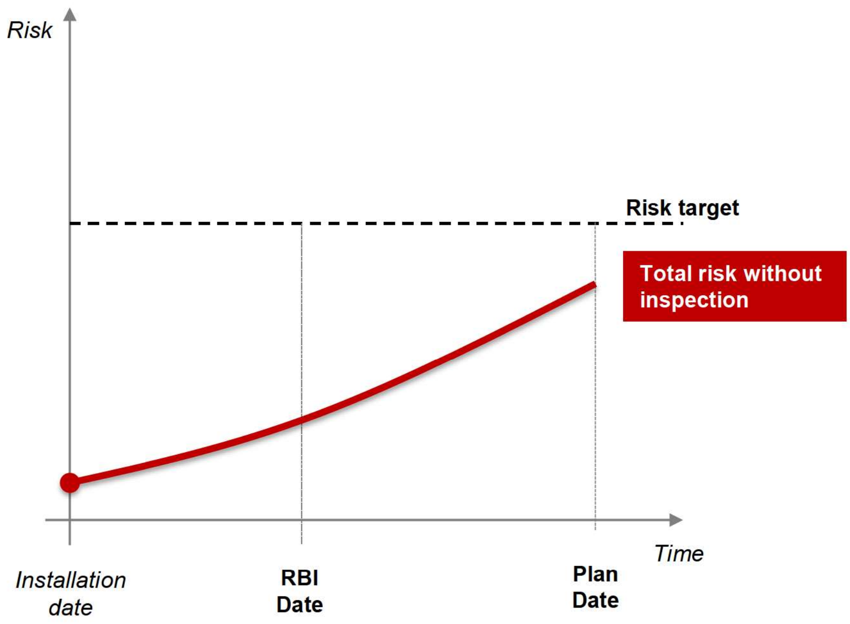
Case 2: *Risk exceeding target prior to the RBI Date*



INSPECTION PLANNING (4/5)

Case 3: ***Risk not exceeded prior to the Plan Date***

- When the risk is determined to be acceptable at the plan date, inspection is not required



INSPECTION PLANNING (5/5)

- The inspection plan is developed based on the three previous cases
- Equipment is modeled as a group of individual components in API RBI
- The final inspection plan for the equipment is based on the results derived for the components
- The inspection plan includes:
  - Date of the required inspection
  - The type of NDT (e.g. Visual, UT, Radiography, WFMT) based on the active damage mechanism
  - The extent of inspection (e.g. percent of total area examined or specific locations)
  - Location of inspection (external or internal)

UT: *Ultrasolic testing,* ***WFMT:*** *Wet fluorescent Magnetic test*

SUMMARY

- As technology and process optimization advances, the context for mechanical integrity in the industry becomes more complex every day
- Other disciplines are starting to follow the rules of quantitative risk-based for their decision-making process
- Inspection team need to produce a step change to become stakeholder in mechanical integrity assurance through risk management
- Quantitative RBI as per API 581 settles the basis for sound risk management of installations

REFERENCES

- API 580 Recommended practice version 2016
- API 581 Recommended practice version 2008 & 2016
- Industry Statistics, TOTAL RC Industrial Division
- Risk-based inspection reassessment, RBI Summit 2009, The Equity Engineering Group

BACKUP

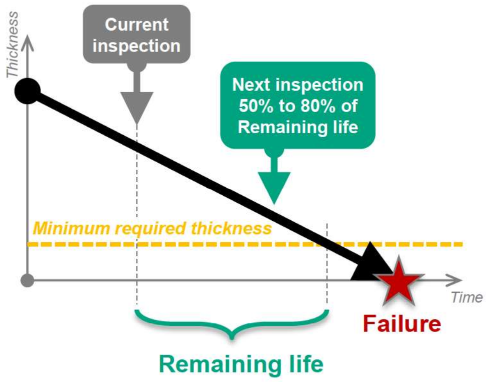
EXAMPLE 2 NEW THINNING MODEL OF API 581

- Version 3 of document released in 2018 contains a new model for assessing POF related to metal loss.
- In general terms this model includes:
  - Determination of furnished thickness, corrosion rate, effectiveness of past inspection and time in service
  - Determination of minimum required thickness through FFS or code calculation
  - Calculate ar/t factor including clad (if exist)
  - Calculate strength ratio using flow stress and the average of tensile & yield stress of the material
  - Calculate the inspection effectiveness factor and the posterior probability depending on those factors (Bayesian approach)
  - Determine the damage factor using affecting the previous calculated parameters by a standard normal cumulative distribution function
  - Affect the calculated damage factor by the on-line monitoring, dead-legs, etc. as in version 2.

***FFS**: Fitness-for-service, **ar/t:** Aging factor (Period.Corrosion rate / Thickness)*

RBI – MAIN CHANGE

REMAINING LIFE



RBI