Risk-based Inspection

Experience of an Oil & Gas operator

TOTAL Energies, France

Tohoku Forum, November 9th of 2023

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Contents

In-service inspection

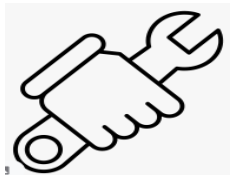
*Inspection actions to **identify degradation** based on **credible industry damage** and failure modes, to determine **further actions** to **control the operational risk**, **predict equipment end of life** and feed the **fitness for service** evaluation*

And not…

Inspection actions to **verify** equipment's **conformity to design code** and determine maintenance actions to **recover its original condition** and **strength**

Inspection approach evolution

Reactive → **Calendar base** → **Condition base** → **Risk base**



Inspection approach evolution

	Reactive	Calendar base	Condition base	Risk base
Strategy	Run to failure	Legal requirement	Equipment life	Risk management
Benefits	Reduced budget	Leveled budget	Reliability assurance	Optimized scope, budget & reliability
Drawback	Costly failures	Costly failures & budget	Feed-back needed	Validity of prediction
RAGAGEP(*)	None	Legal text	**API Codes:** Vessels 510, Piping 570, AST 653, Heaters/Boilers 573, PSV 576	**API 580** *supported by* **581, 571 & 584**

(*) Recognized And Generally Accepted Good Engineering Practice

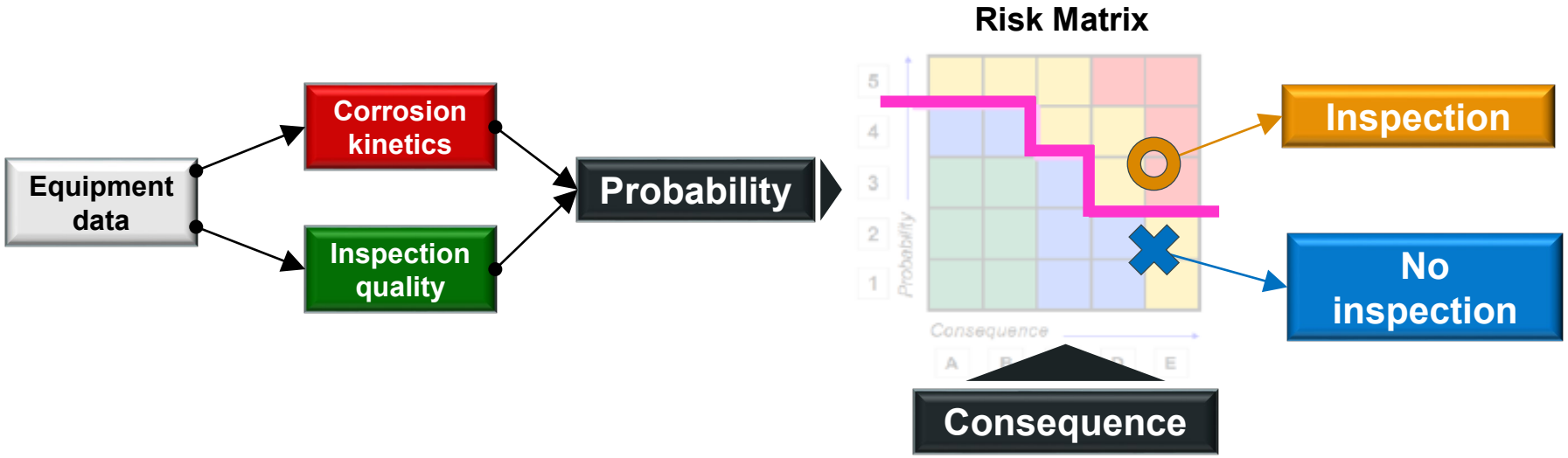
RBI, a systematic proces that...

Begins with ***identification of facilities*** or equipment

Continues with a ***determination of risk,*** via probability and consequence of failure

And culminates in the creation of an ***inspection risk-based management plan*** based on the credible damage mechanism(s) and the risk of failure

Inspection teams should utilize the RBI output to ***effectively and efficiently prioritize*** the execution of their ***inspection programs***



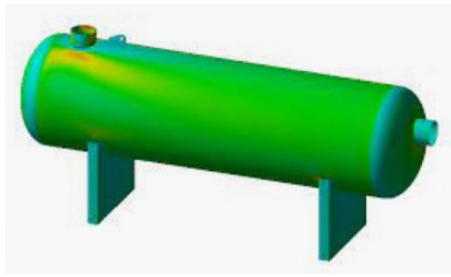
Aimed to provide minimum elements for…

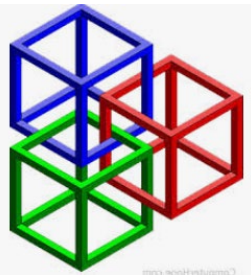
Developing, implementing, and maintaining inspection programs

Of ***pressure-containing*** equipment

To insure ***safe and reliable operation*** through ***risk-prioritized inspection***

Through a ***framework*** that specifies the ***minimum requirements*** and expectations needed for a ***quality application*** of the methodology



Same case, different strategies

Ractive

Visual internal inspection, CA not affected
Next inspection **eventually upon equipment opening**

Calendar

23,9 > 21,3 → OK
Corroded area repair by welding
Next inspection in **2023, internal**

Data

CS drum ϕ 2,5m T_{orig} 25,4 mm
DP 20 bar DT 38°C CA 3 mm
T_{min} 21,3 mm
Internal inspection in 2018:
Local corroded area 1,5 mm deep since 2013
Corrosion rate 0,3 mm/an.

Condition base

R_{life} 13,6 yrs., ½ in 2025 (API 510)
Next inspection in **2023, internal**

Risk-based

Generic frequency 3E-05, Management factor 0,4
Increased CR to 0,5 mm/yr. due to process change since 2015 yrs.
Highly effective inspection
Timeframe 9,2 yrs. To 2027, DF 8,2 POF = GFF x MF x DF = 1,02E-04 (Level 3), COF = Major
Next inspection in **2027**, **non-intrusive by UT Scan**

Benefits

Identification of damage mechanisms and failure modes

Identification of equipment with insufficient or inadequate inspection history

Safety, health, and environmental and/or economic consequences

Recommendation of inspection methods and techniques

Establishment of the extent of inspection

Optimum inspection interval

Development of cost-effective actions

Overall reduction in risk for the facilities

Other required mitigation

Integrity and reliability improvement at the same time

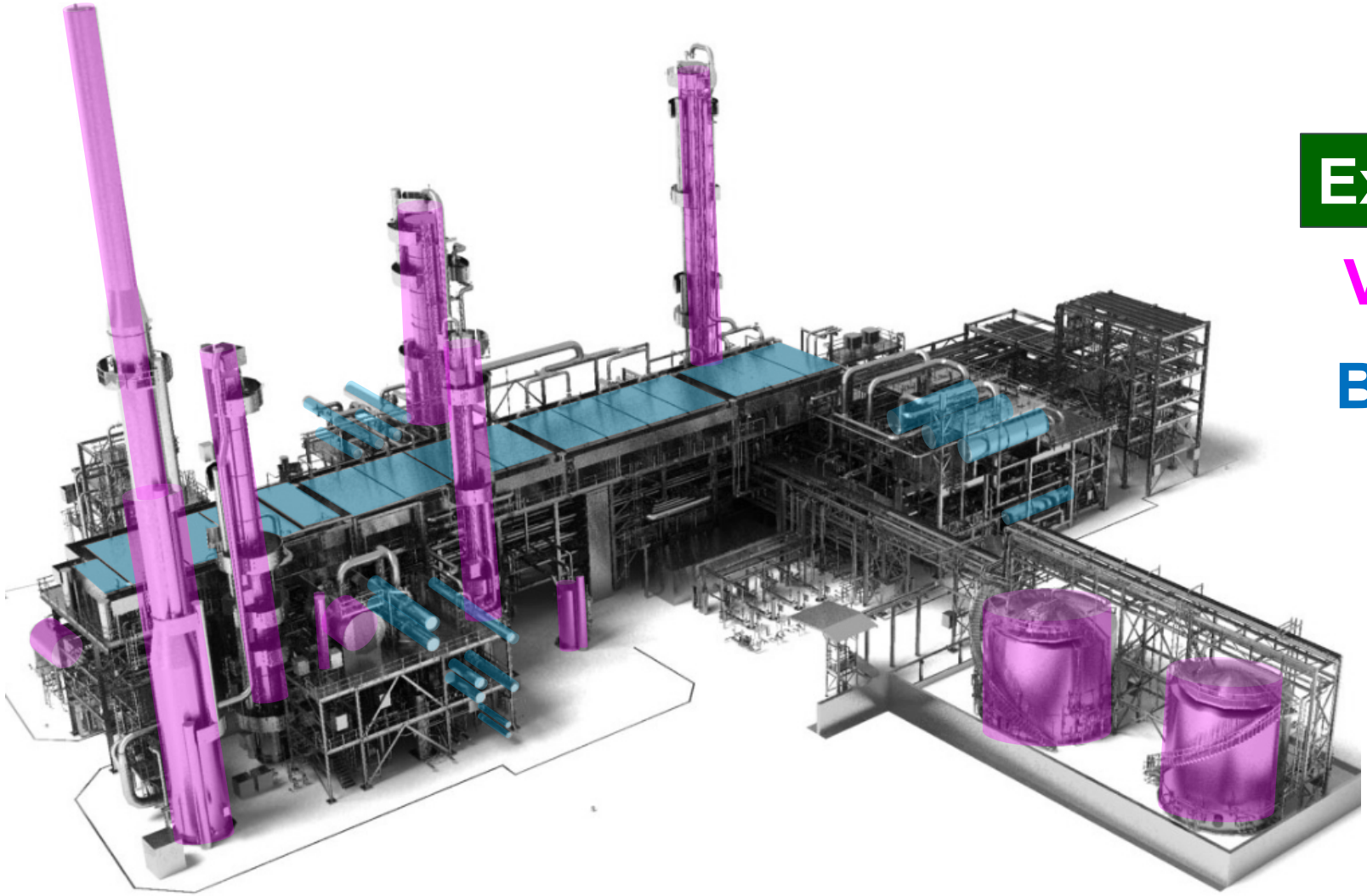
RBI limitations

- RBI does not compensate for mistakes due to lack of skills on inspection
- The effectiveness of an inspection can be limited
  - Lack of coverage
  - NDT limitations
  - NDT procedures and technician skills

Richmond fire learnings

- 6 injured & unit destroyed)
- Corrosion by Sulphidation
- No awareness of increasing temperature and opportunity crude processing
- No program for low silicon CS
- No history of spool change => no dedicated CML

Typical oil Refinery



Exposed surface	
Vessels	9%
Bundles	35%
Piping	56%

Unbalanced inspection effort

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%

- *83% on 9% of exposed surface that produces 10% of problems*
- *16% on components leading to 78% of leaks*
- *1% on reliability bad actors*

History of RBI in TotalEnergies

1990-93	Company became sponsor of RBI from the API
1995-99	First qualitative RBI Guide for vessel and piping
2000-03	Company develop their own RBI software with an expert body
2004	French inspection guide allows using RBI to optimize inspection periodicities
2007	Important increase of maintenance cost due to inspection request
2008-10	First quantitative RBI guide for Refining, based on regulations flexibility
2011-12	Cultural change need identified. Communication, Audits and the concept of acceptable risk installed Improvement of Integrity operating windows and Fitness-for-service also launched

Criticality based model

History after concept change

2011-12	Cultural change need identified. Communication, Audits and the concept of acceptable risk installed Improvement of Integrity operating windows and Fitness-for-service also launched
2013-17	Deployment RBI and inspection effectiveness training and coaching and the implementation of turnaround scope reviews
2018-19	Refining & Chemicals deploy a New RBI software
2020	Concept of Dynamic RBI starts to be largely used for turnaround postponement assessment due to COVID
2021-23	RBI software completed in Refining and Chemicals and RBI concept and new software started in Exploration and production facilities

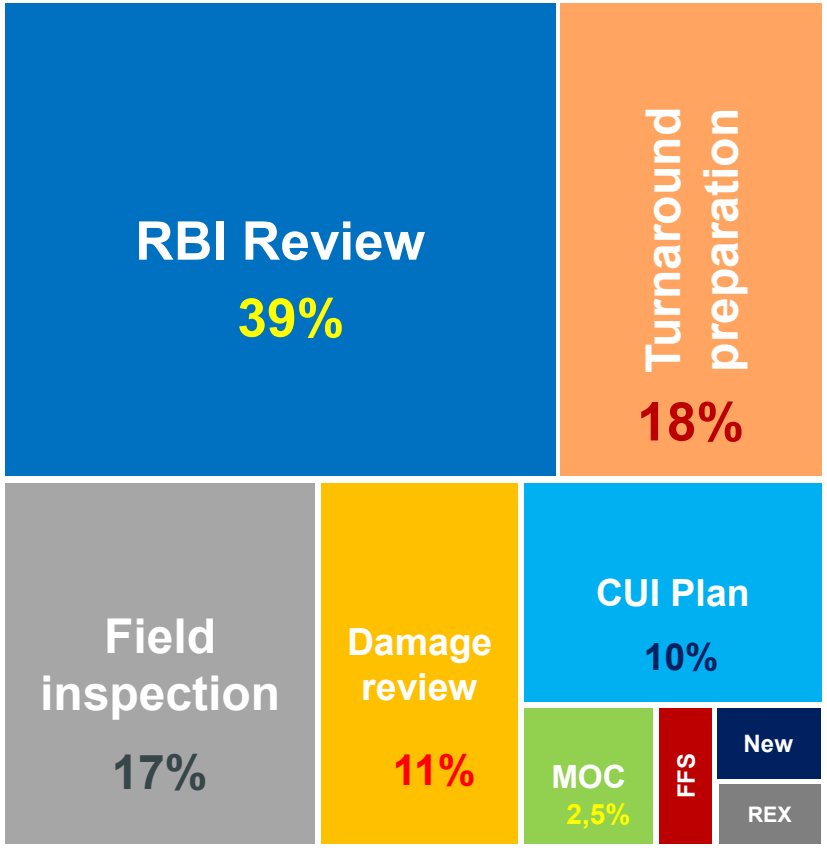
Risk-based

Framework of an RBI-like inspection team

- 9 big domains, 54 workflows and 222 tasks

Main tasks & workload of a typical refinery

- Method inspector, main actor to keep RBI up-to-date
- In-house Unit inspector and assistant mostly dedicated to plan & inspect
- External Unit inspector helps on planning and Turnaround preparation



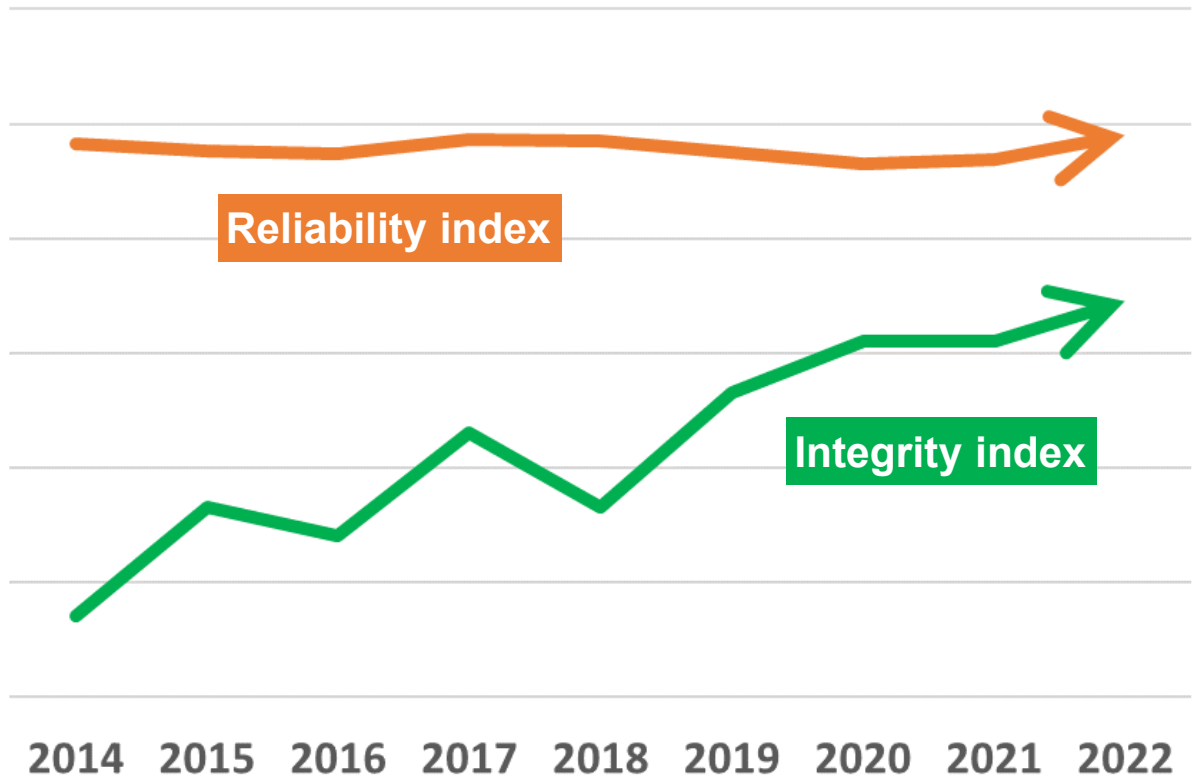
Main workload estimation (MH/yr. medium size refinery)				
Method inspector		3500	Corrosion update (IOW issue)	13%
			RBI update	13%
			Special RBI (Non-model, etc.)	13%
Unit inspector	In house	2300	Field inspection	93%
			Assessment following issues	4%
	External	3400	Inspection planning	25%
			QA review	17%
			Turnaround preparation	11%
Assistant Inspector		2100	Inspection planning	44%
			Inspection facility request	11%
			Corrosion loop update	11%
Other *(Process, Corrosion, FFS, etc.)*		1800		

Additional methods and tools

- Some components not well managed by the RBI models and software's
- Also, some damage mechanism are not modelized, and require a special approach
- Creep damage can be managed through FFS dedicated tool instead of RBI
- RBI for exchanger bundles can be supported by statistical analysis and tools
- Statistical evaluation of corrosion rate should be supported by special tools
- Management of risk beyond RBI can be supported by multidisciplinary Layer of Protection Analysis (LOPA)
- Risk-based cost/benefit assessment tools helps on financial decision making

Leading indicators

- Early result showed important reduction of inspection workload, mainly during Turnarounds
- Inspector cultural change progressively followed of the approach acceptance from Authorities
- Integrity index showed improvement while reliability index remined stable



Probability of failure calculation

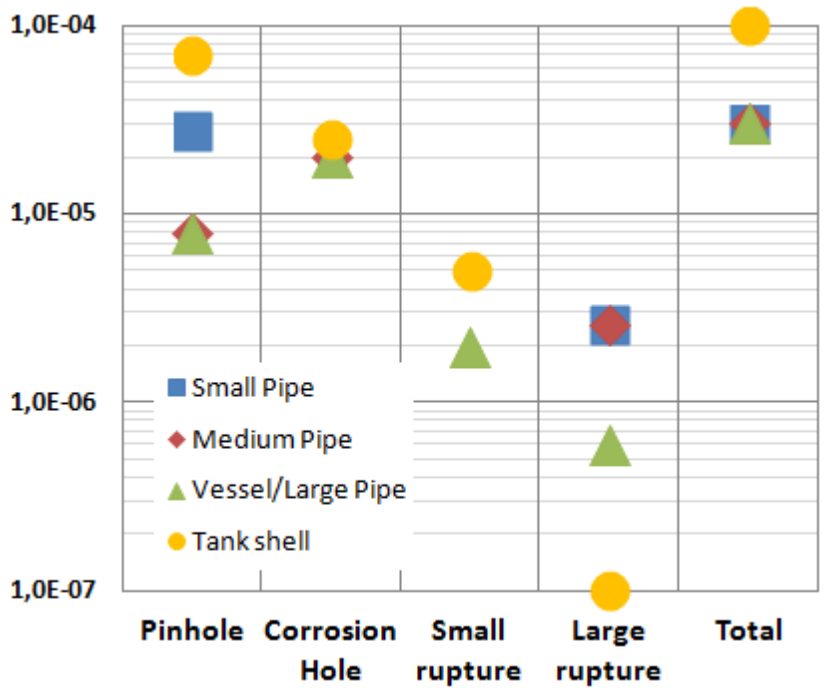
- The probability of failure in API RBI is determined by three parameters:
  - Generic failure frequency
  - Damage factor
  - Management system factor

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

Based on industry data

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

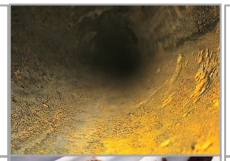
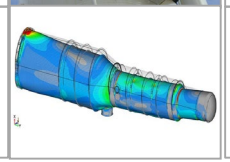
Generic failure frequency



Damage factor calculation

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

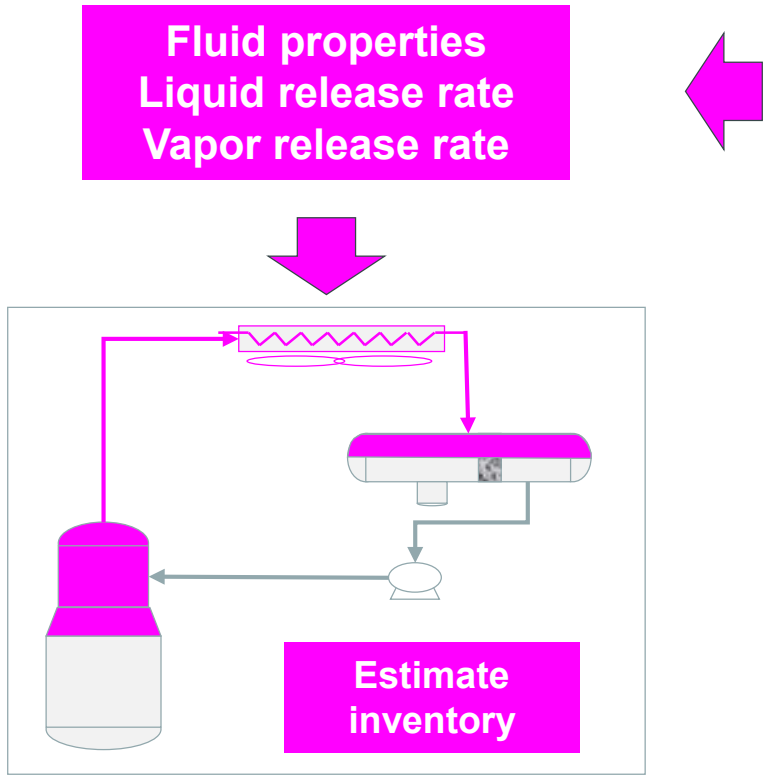
$$POF(t) = gff \cdot D_f \cdot F_{MS}$$

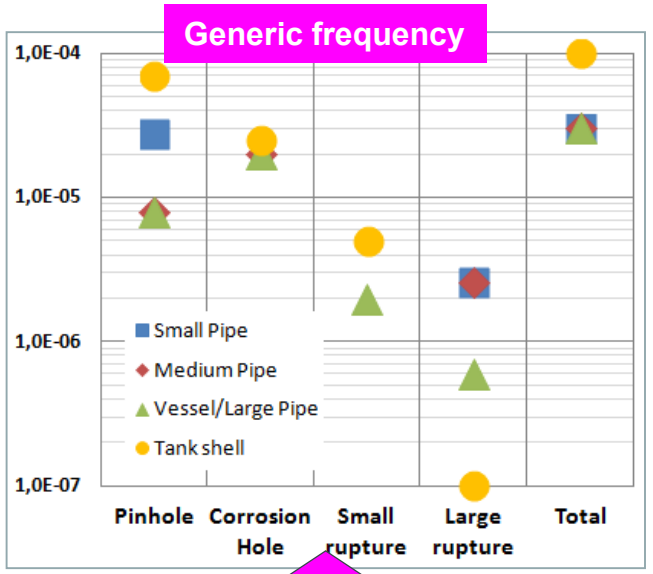
D_f^{thin}		Internal corrosion
D_f^{elin}		Lining damage
D_f^{extd}		External corrosion
D_f^{scc}		Stress corrosion cracking
D_f^{htha}		High temperature H_2 Attack
D_f^{brit}		Brittle fracture
D_f^{mfat}		Mechanical fatigue

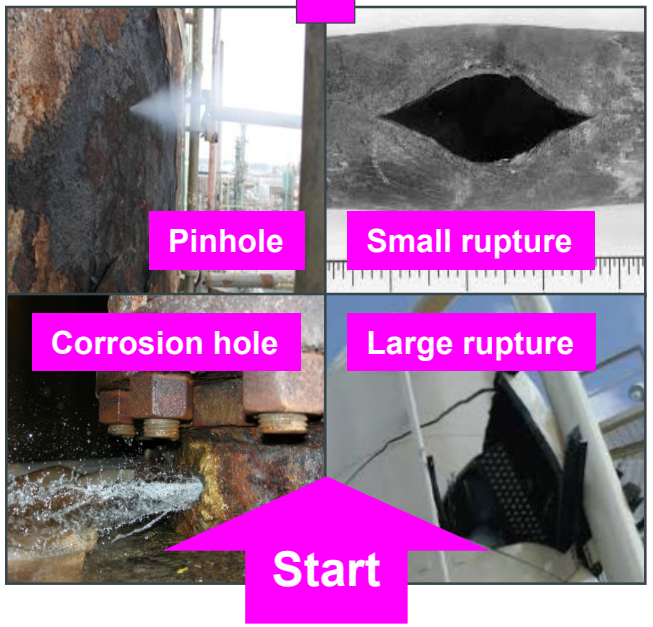
$$D_{f\text{-}total} = min\,[\,D_f^{thin}, D_f^{elin}\,] + D_f^{extd} + D_f^{scc} + D_f^{htha} + D_f^{brit} + D_f^{mfat}$$

Fluid inventory calculation

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

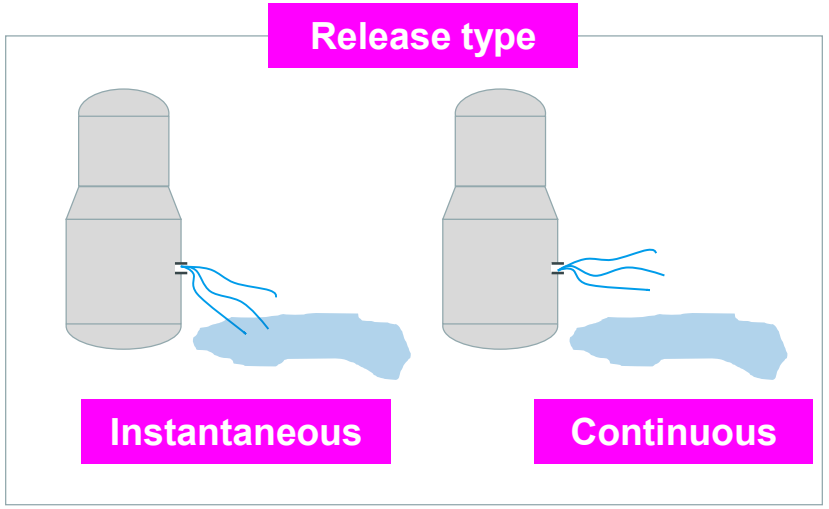


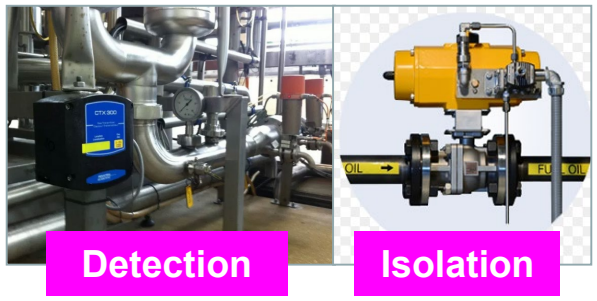




Type of release estimation

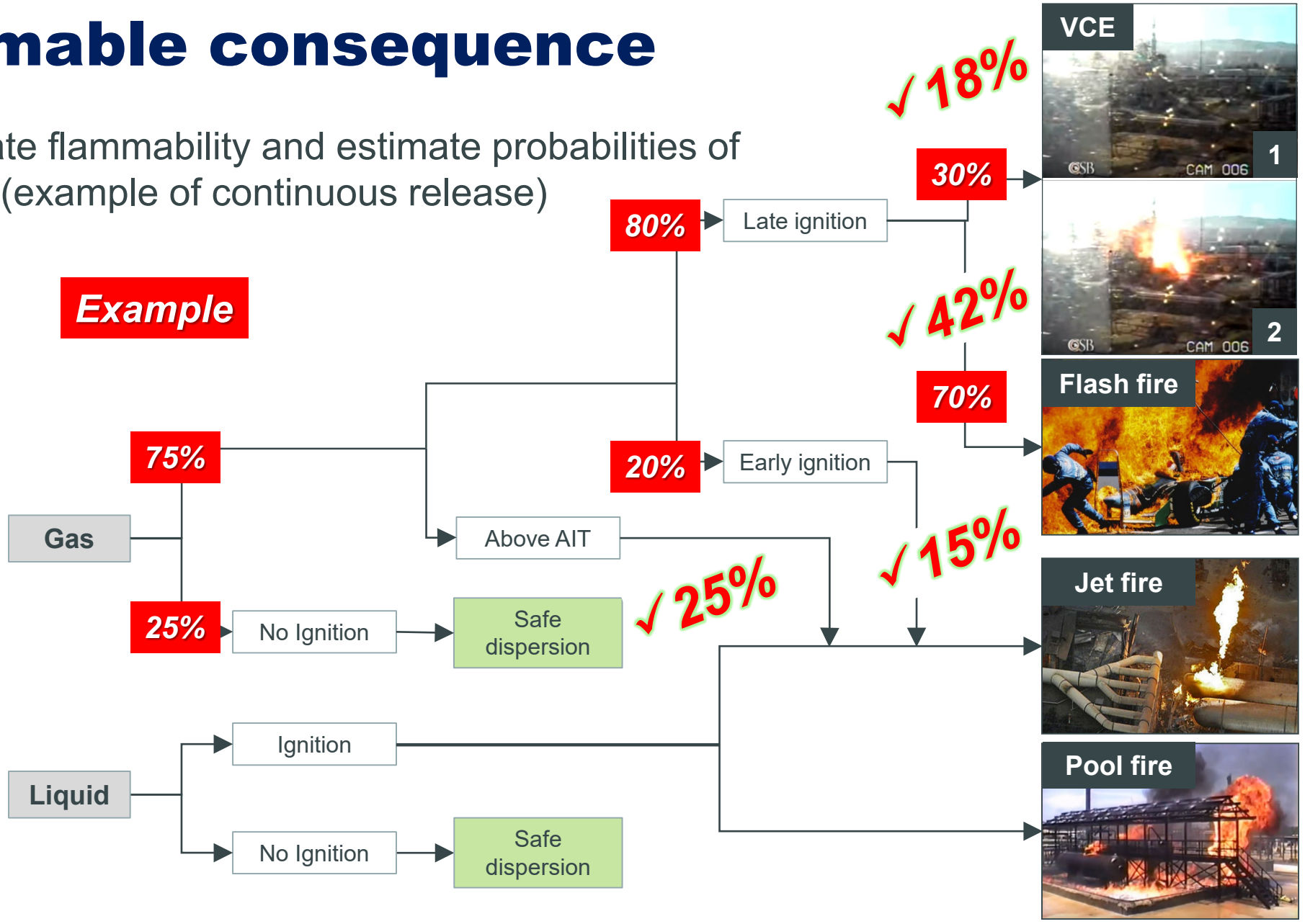
- Determine release type and assess detection and isolation systems





Flammable consequence

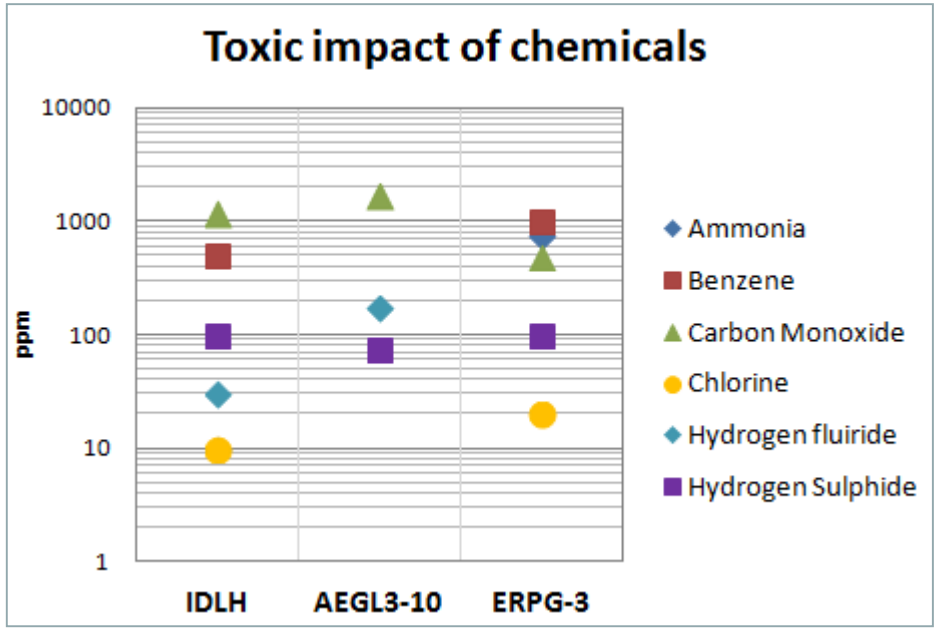
- Calculate flammability and estimate probabilities of events (example of continuous release)



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

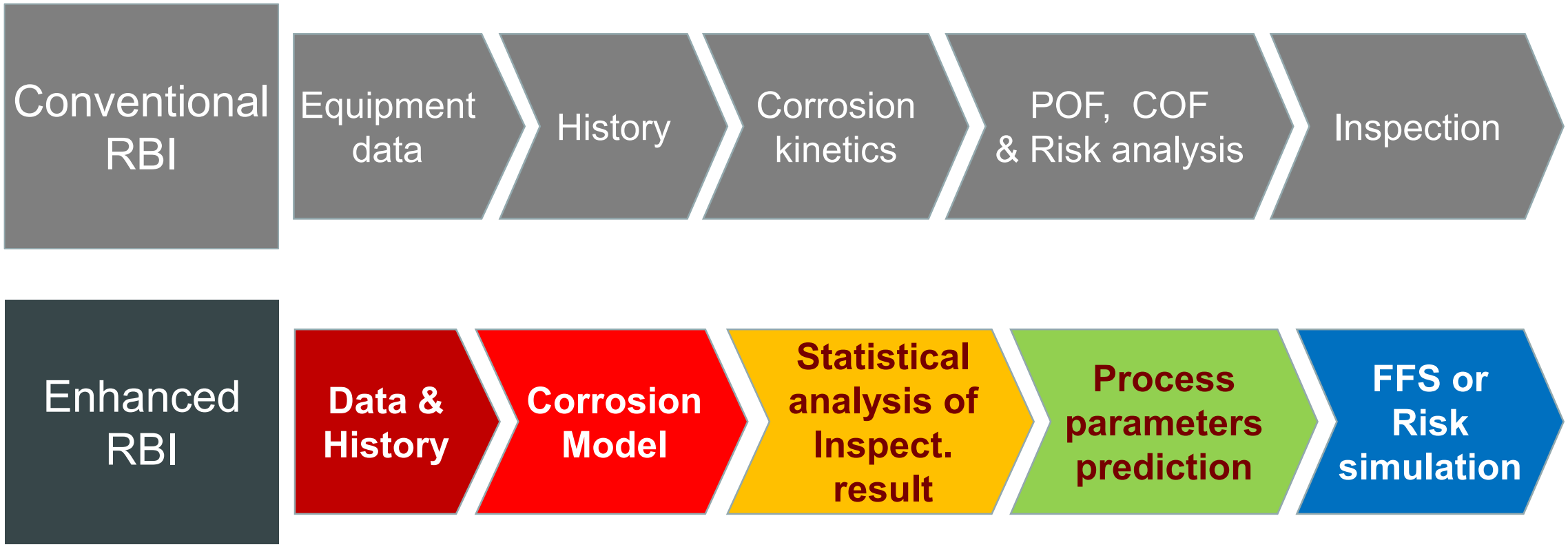
Other consequences

- 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*

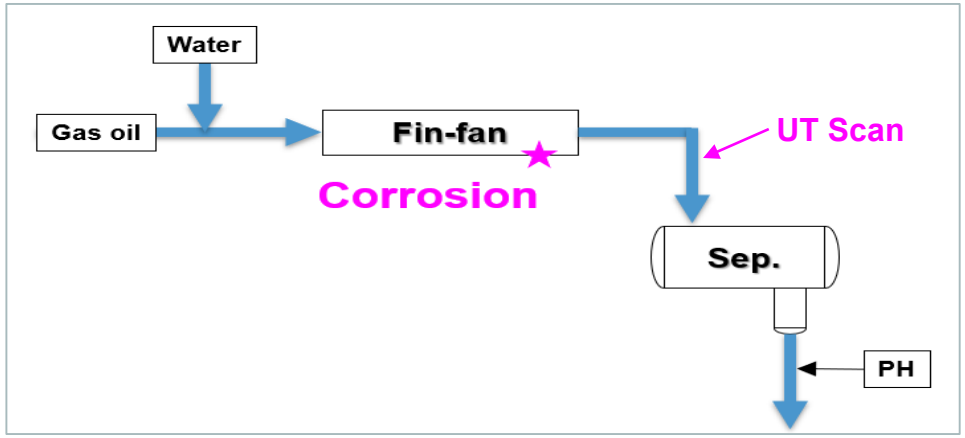
Inspection entering the digital era

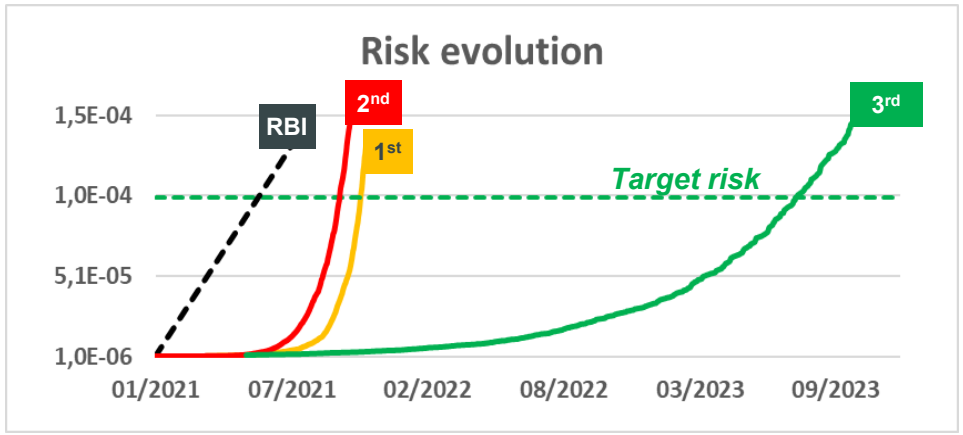


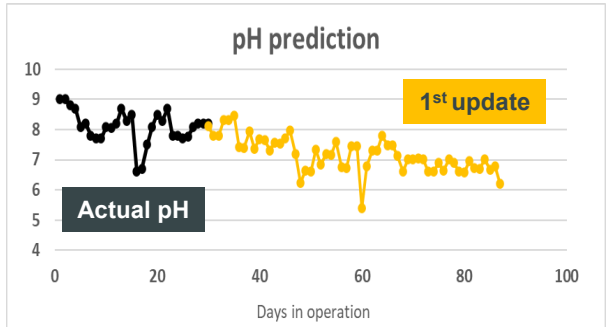
POF: *Probability of failure* ***COF:*** *Consequence of failure,* ***FFS:*** *Fitness-for-service*

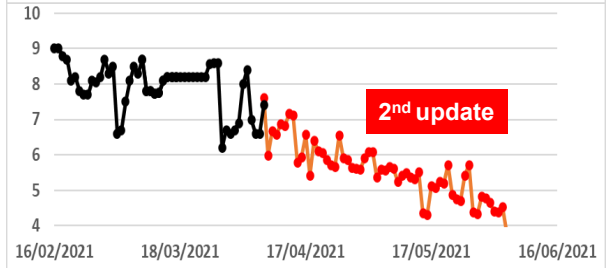
Example

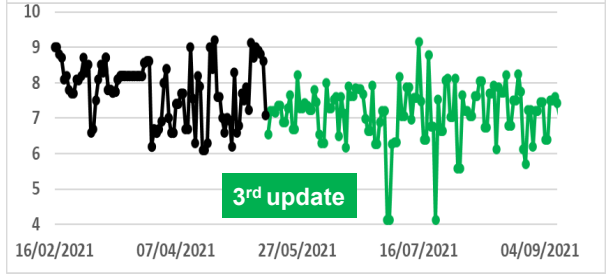
- Following corrosion issue in 2020, a Fin-fan's conventional RBI asked inspection mid 2021
- Process improvements led to mitigate corrosion, but RBI at fixed corrosion rate could not managed this improvement
- Enhanced RBI applied and updated once a month
- Outlet line used as inspection monitoring location once a month
- Turnaround moved to September 2023 instead of 2021



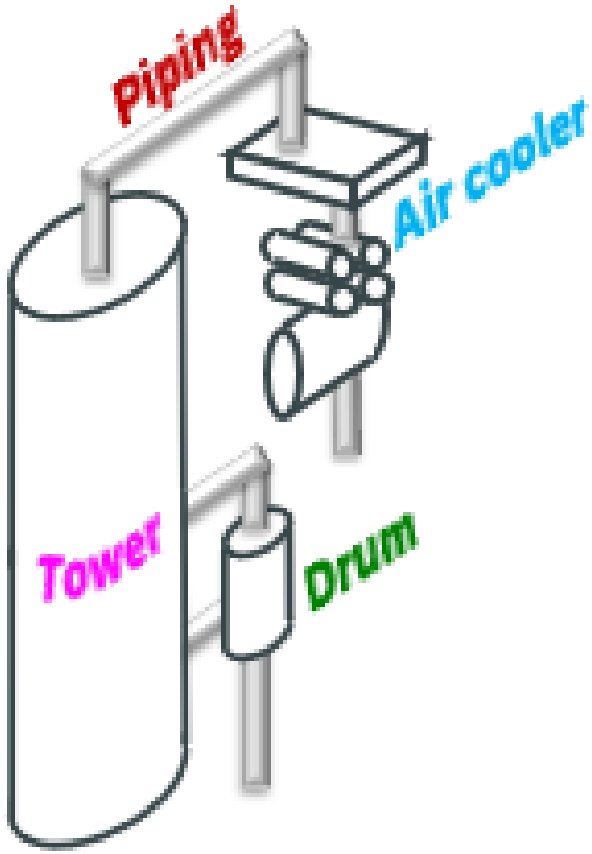








Digital transformation of Inspection



Approaches & context

Step	Approach	Piping	Equipment	Extrapolate to?	Inspector	Field insp. / NDT	Engineer	Data scientist
1	Calendar	Visual	None	None	2	1		
2	Condition	TML & RLife	Visual + spot UT	None	2	2		
3	RBI	Fixed CR	RBI + corrosion model	None	1	1	1	
4	Enhanced RBI	Dynamic RBI	Risk & FFS simulation	Connected equipment	½	1	1	½
5	Smart integrity	Machine learning applied to process & inspection history	Damage & risk simulation	All Refinery		1	½	1
6	Digital integrity	Machine learning update applied to process data and fixed field captors		All Refinery	?			

Summary and conclusions

- Understanding the risk-based decision-making process is a key of success
- Integrity improvement should be highlighted first
- Cultural change rather coming from training and coaching
- Deployment & update effort must be optimized and audited, don’t create monsters!
- Scope review from knowledgeable central office help to assure world class performance
- Integrity operating windows essential for the credibility of conventional RBI internal corrosion management
- Additional tools required to support change management
- Management of risk beyond RBI essential for integrity assurance
- Digital RBI must follow and should be managed with care due to implications on skills, manpower and regulations

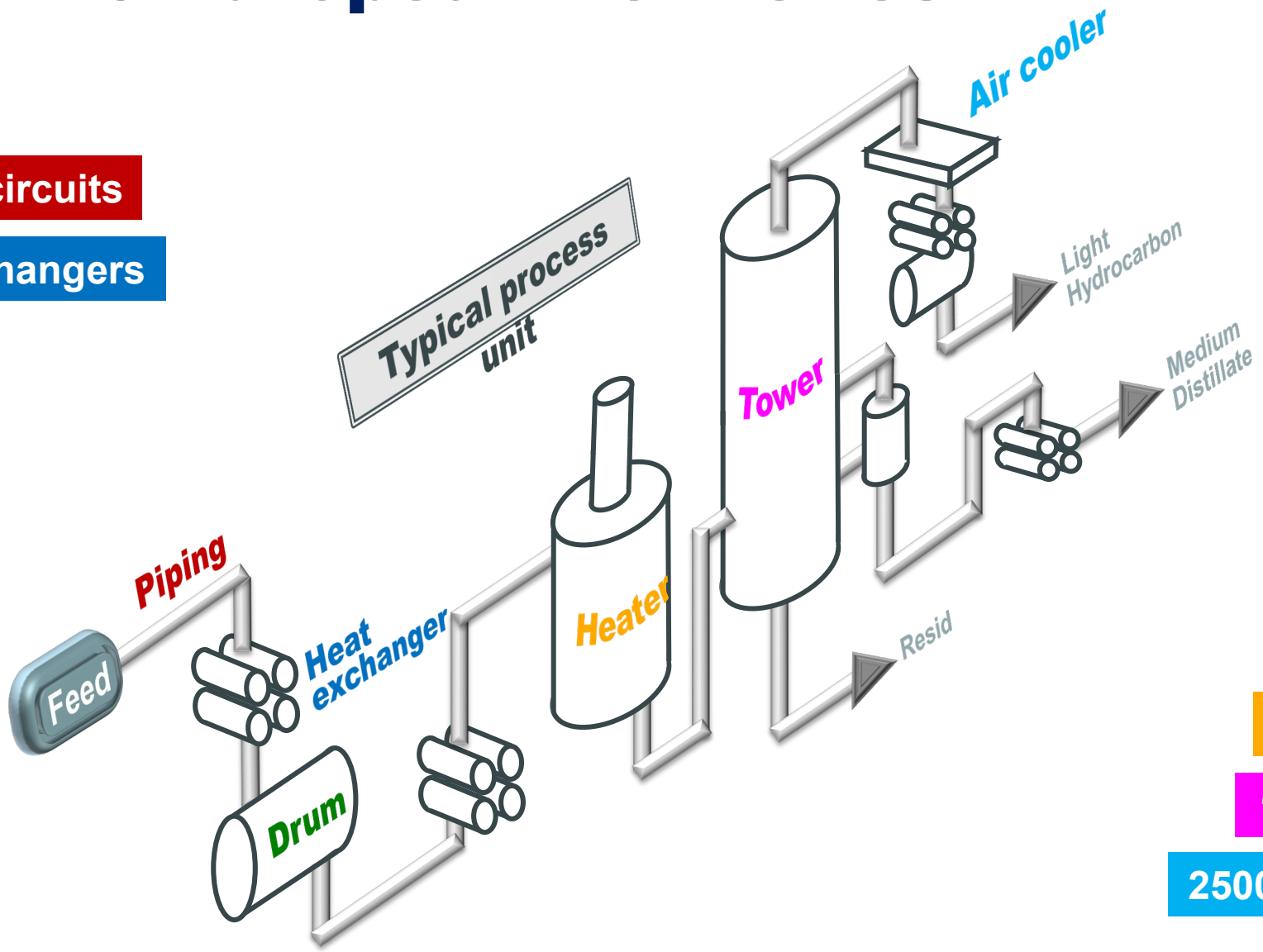
Backup

Context of 10 European Refineries

27000 Piping circuits

9000 Heat exchangers

8000 Drums



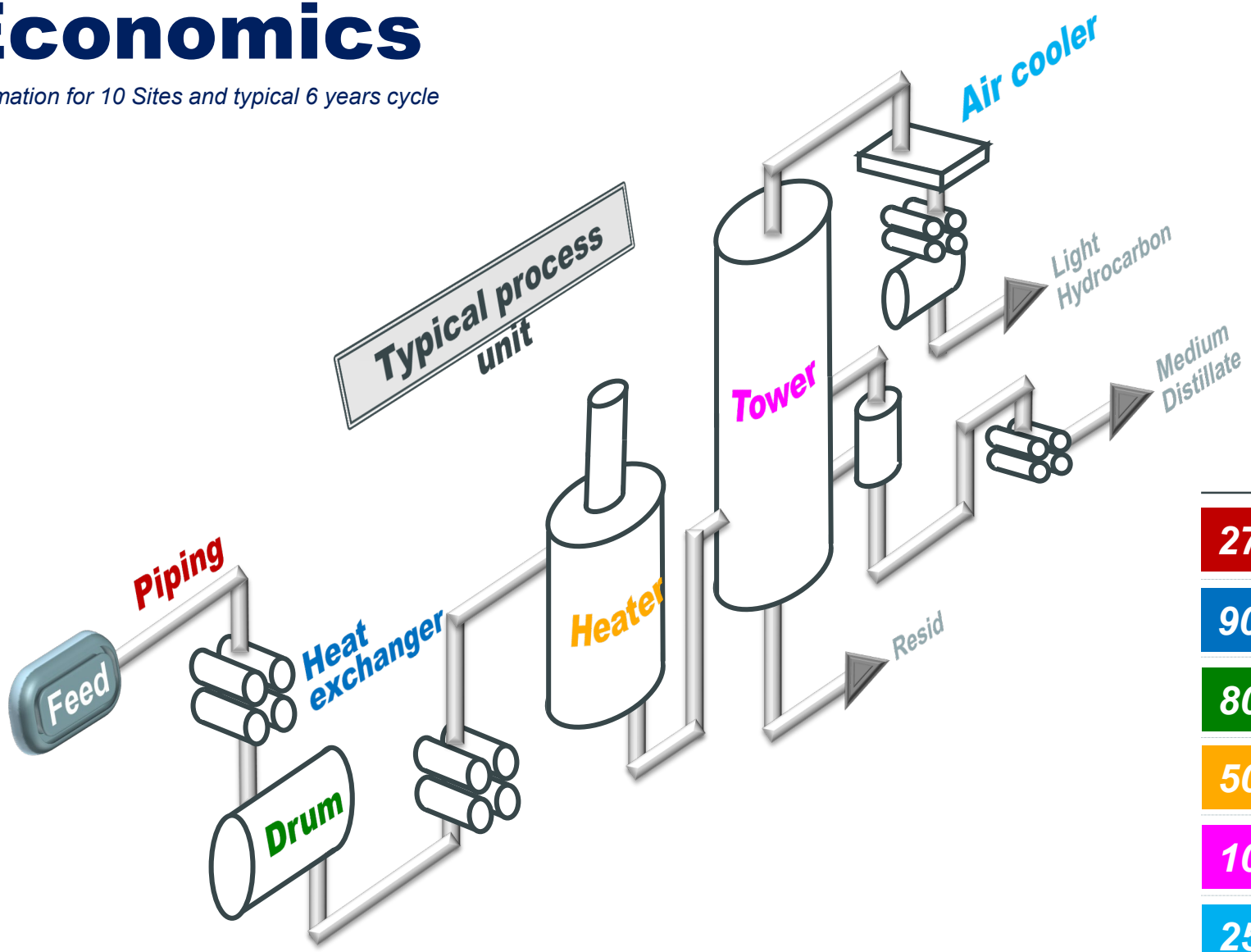
500 Heaters

1000 Towers

2500 Air coolers

Economics

Estimation for 10 Sites and typical 6 years cycle



	Global saving *% with RBI*
27000 Piping circuits	-50%
9000 Heat exchangers	42%
8000 Drums	50%
500 Heaters	20%
1000 Towers	50%
2500 Air coolers	42%
Global	**26%**

RBI basic requirements

Risk base

Risk management

Optimized scope, budget & reliability

Validity of prediction

- ✓ Integrity assurance strategy based on **risk management**
- ✓ **Stick to risk-based** upon decision-making approaches
- ✓ Implementation of **solid monitoring of process variables** related to degradation
- ✓ Assure **effective management of change**

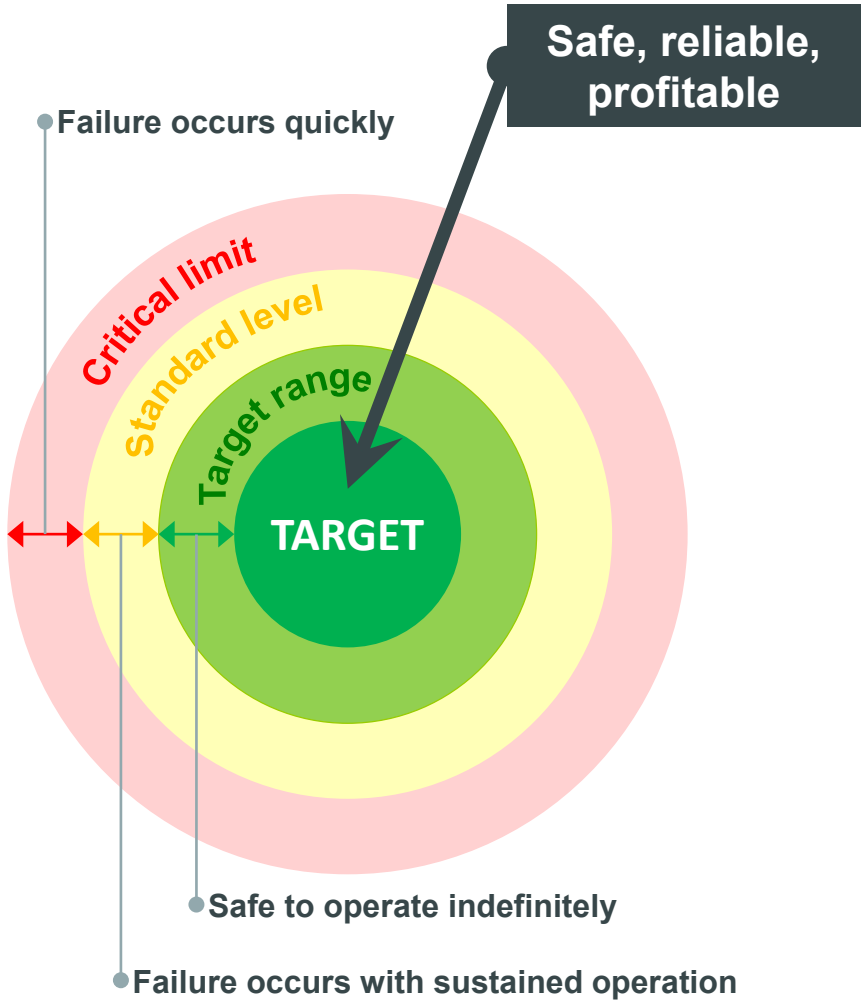
Integrity operating windows

Structured analysis

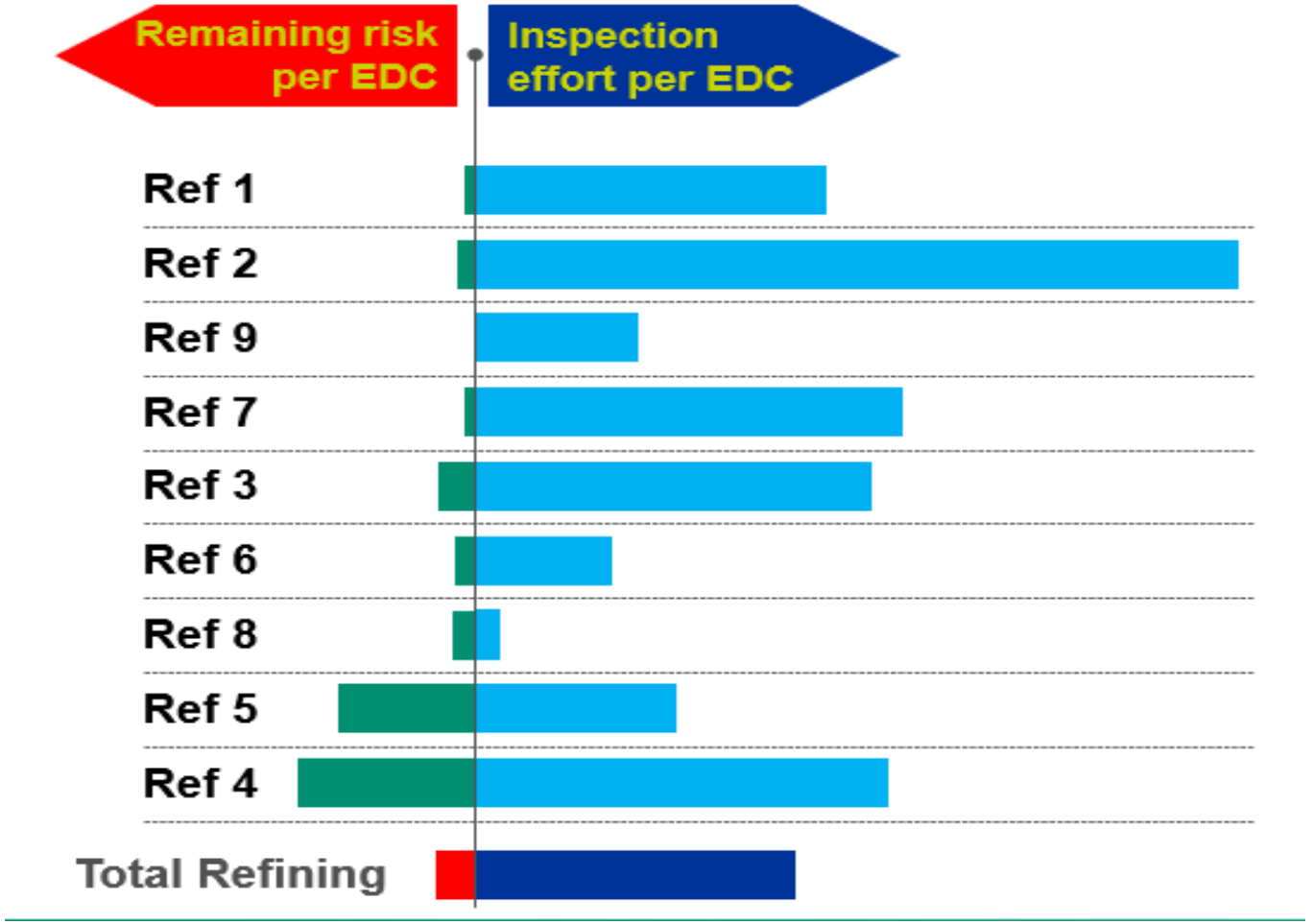
- Review parameters, kinetics and the damage mechanism
- Review current plan (inspection date)
- Assess if RBI can be jeopardized, if yes, trigger deep assessment
- Record the analysis

Examples oof IOW violations

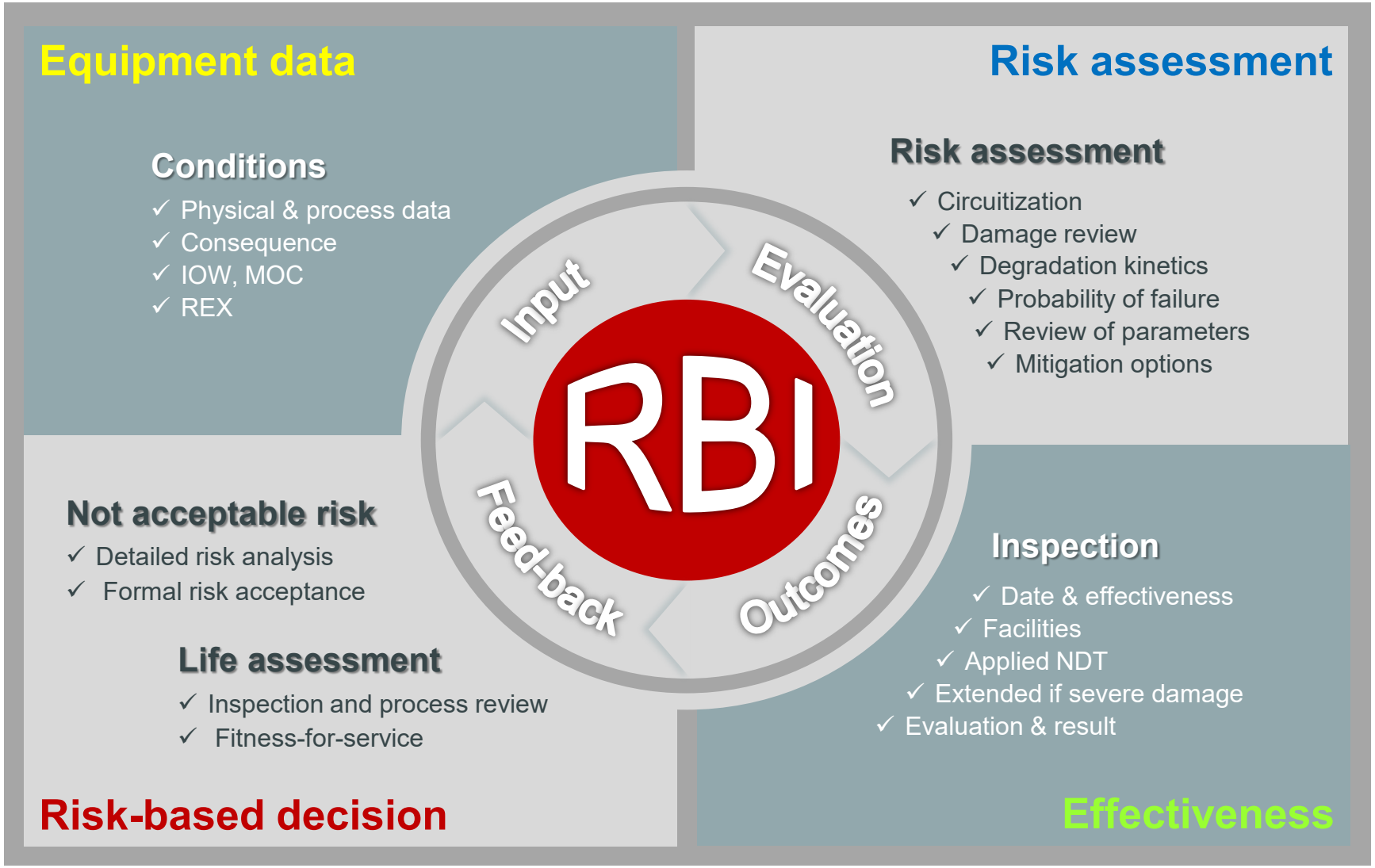
- Change in the fluid's Sulphur content
- Stop of corrosion inhibitor injection
- Change in the pH or fluid chemical composition
- Cathodic protection not working/not under control



RBI performance in 2011



Inspection framework



Inspection manager main responsibilities

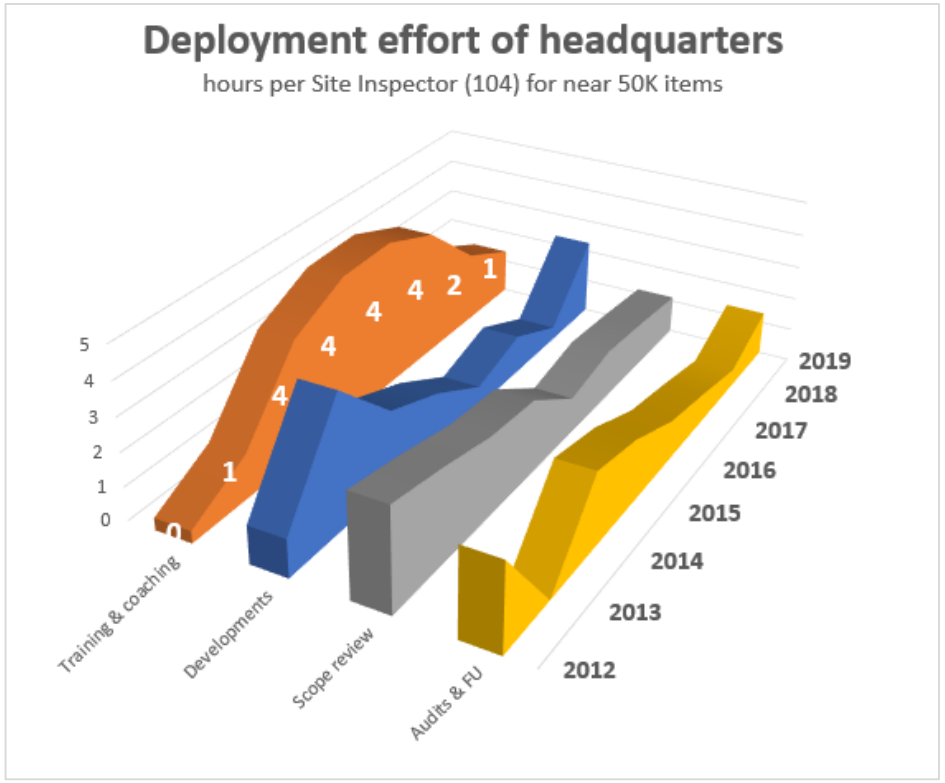
- Inform Site management of non-acceptable risks
- Set-up inspection policy
- Assure inspection plan
- Inspection activity tracking and reporting
- Ensure training and skills of Inspection personnel
- Manage inspection activities
  - Role and responsibilities of Inspection team
  - Track inspection schedule recommendations
  - Use of FFS
  - Manage and optimize Inspection associated costs
  - Maximize on-stream non-intrusive inspections
  - Assure resources
  - Implement best-practices
  - Deploy new NDT technology

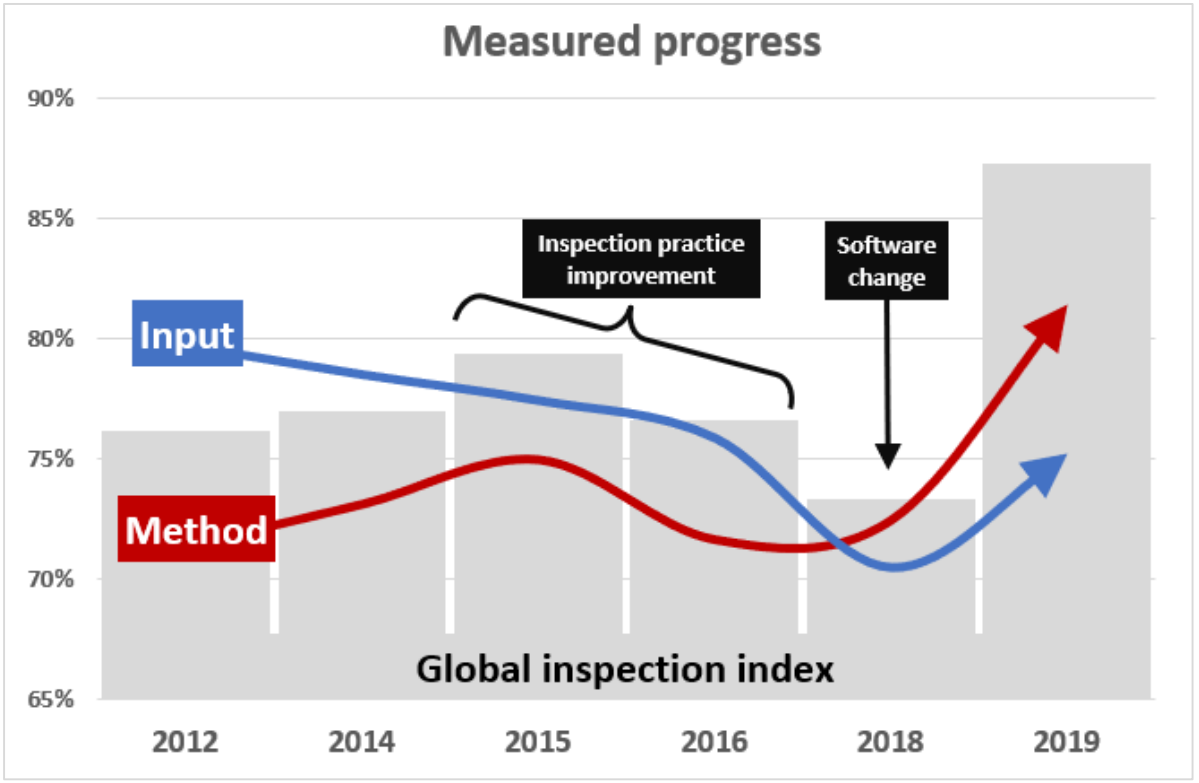
Inspection team duties

- Implement inspection methods
- Outline inspection plans
- Assess inspection results and write inspection reports
- Ensure monitoring of corrosion/degradation issues
- Ensure application of fitness-for-service
- Manage database and equipment history records
- Provide information for inspection budget preparation, cost tracking, annual review and inspection Contracts
- Provide advice and supervision on quality assurance activities

RBI deployment in downstream

- Deployment RBI means a big Company effort and a « users » cultural change
- Based on experience, a cycle of > 6 years must be considered
- A combined effort of Development, communication, training and audit need to be put in place





Example of upstream

- 5 weeks deployment for CPF and 23 for a FPSO
- Core team of 4 Inspectors that can be outsourced
- 3 Engineers (Site or Outsourced)
- 10 assistants and clerks that can provide the Site (to adapt based on complexity)

Item	Onshore (CPF)	Offshore (FPSO)
Equipment	362	1599
Part	378	1766
Main units	1	7
Inspection task	756	3532

Position	Team	CPF		FPSO	
		Weeks	*Duration*	*Weeks*	*Duration*
Method inspector	2	7	4	40	20
Unit inspector	2	10	5	49	24
Assistant inspector	4	25	6	139	23
Corrosion Eng.	1	1	1	6	6
Process Eng.	1	2	4	14	27
Valoriz. Eng.	1	1	2	10	10
Maintenance Eng.	1	1	2	10	10
Clerk	4	4	5	98	24

Inspection entering the digital era

- RBI, the **best platform** for **integrity** and **business-related** decision making
- It still **heavily rely** on **expert** judgment
- **Corrosion rate** determination leads to frequent **pit falls**
- Strongly **improvement** through **IOW**, but not easy to **integrate into RBI**
- **Process control** not under use to drive **risk determination**

Questions to answer

- ✓ Is RBI & integrity operating windows enough?
- ✓ Continue to rely on expert judgment case by case?
- ✓ What are the alternatives?
- ✓ How degradation works?
- ✓ What if using prediction models based on process control and use Inspection as a calibration factor?