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WHEN TRUST MATTERS

使用 RBI 進行設備腐蝕評估

SY-12-TC 量化RBI與資產完整性管理課程

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29 June 2023

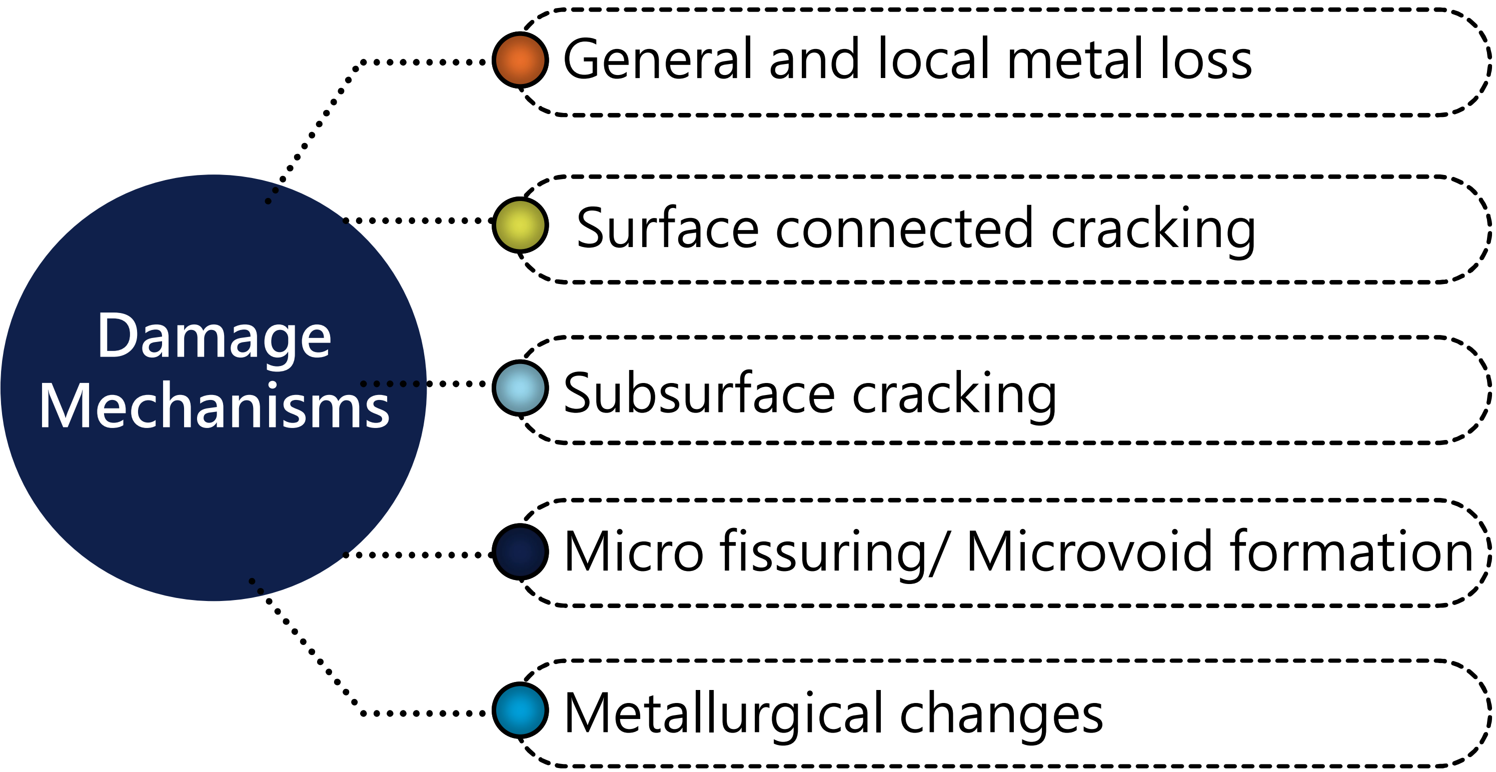
目錄

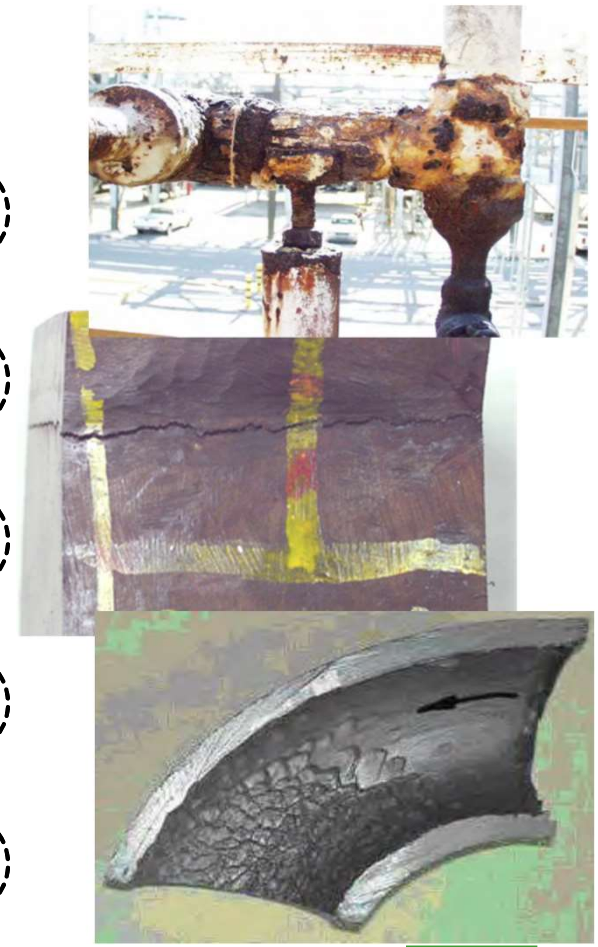
- Damage Mechanism
- Damage Mechanism and RBI
- Corrosion Circuit

Damage Mechanism

Damage Mechanism

- A damage mechanism (DM) is any type of potential cause of failure, problems, or corrosion.
- There are many potential damage mechanism, including forms of corrosion and cracking, thermal damage, wear and abrasion.





DM-API reference code

- API 570 Piping Inspection Code: In-service Inspection, Rating, Repair, and Alteration of Piping Systems
  - 5.4.1 Piping System Damage Types
- API 510 Pressure Vessel Inspection Code: In-service Inspection, Rating, Repair, and Alteration
  - 5.4 Inspection for Different Types of Damage Mechanisms and Failure Modes
- API RP571 Damage Mechanisms Affecting Fixed Equipment in the Refining Industry
  - 67 type Damage Mechanisms
- API RP581 Risk-Based Inspection Methodology
  - Part 2—Probability of Failure Methodology
- API RP970 Corrosion Control Document Systems
- API RP584 Integrity Operating Windows

Damage Types for process piping systems and Pressure vessel

API 570
Process piping systems

Metal loss

- ✓ Sulfidation
- ✓ Oxidation
- ✓ MIC
- ✓ Naphthenic acid corrosion
- ✓ Erosion-corrosion
- ✓ Galvanic corrosion
- ✓ Atmospheric corrosion
- ✓ CUI
- ✓ Soil corrosion
- ✓ Carbon dioxide corrosion
- ✓ Chloride corrosion

Cracking

- ✓ Mechanical fatigue cracking
- ✓ Thermal fatigue cracking
- ✓ Caustic stress corrosion cracking
- ✓ Polythionic stress corrosion cracking
- ✓ Sulfide stress cracking
- ✓ Chloride stress corrosion cracking
- ✓ Wet H2S damage

High-temperature

- ✓ High-temperature hydrogen attack
- ✓ Creep / stress rupture

Metallurgical changes

- ✓ Graphitization
- ✓ Temper embrittlement
- ✓ Hydrogen embrittlement

API 510
Pressure vessels

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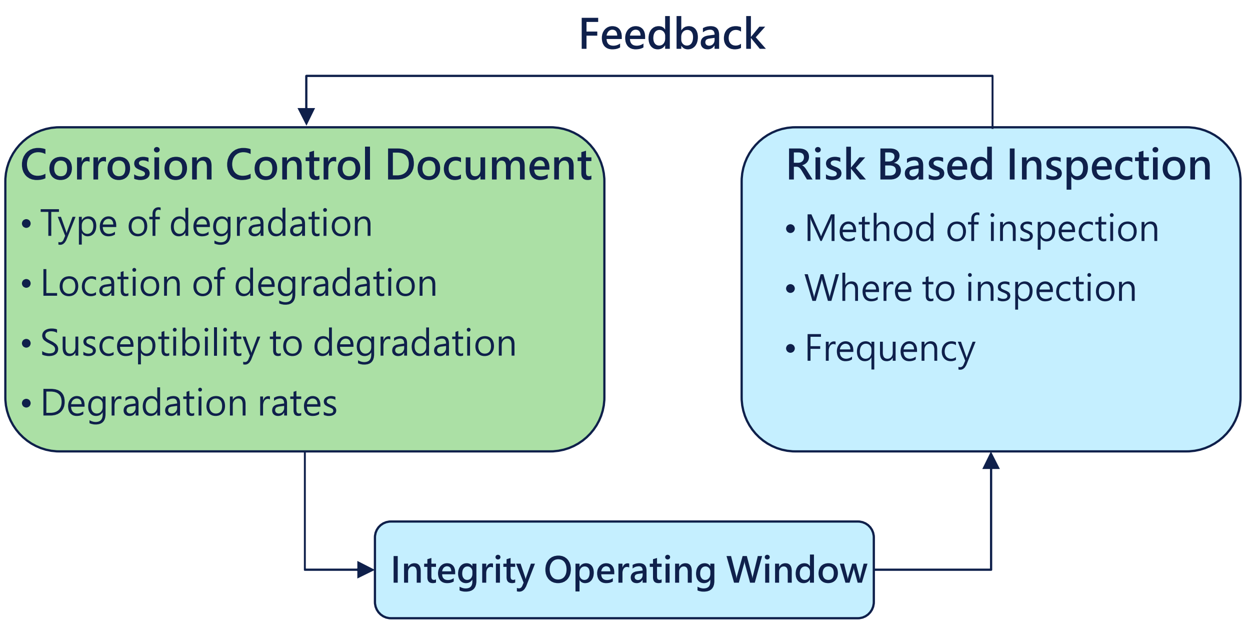
Corrosion Control Documents

Key Components of CCD

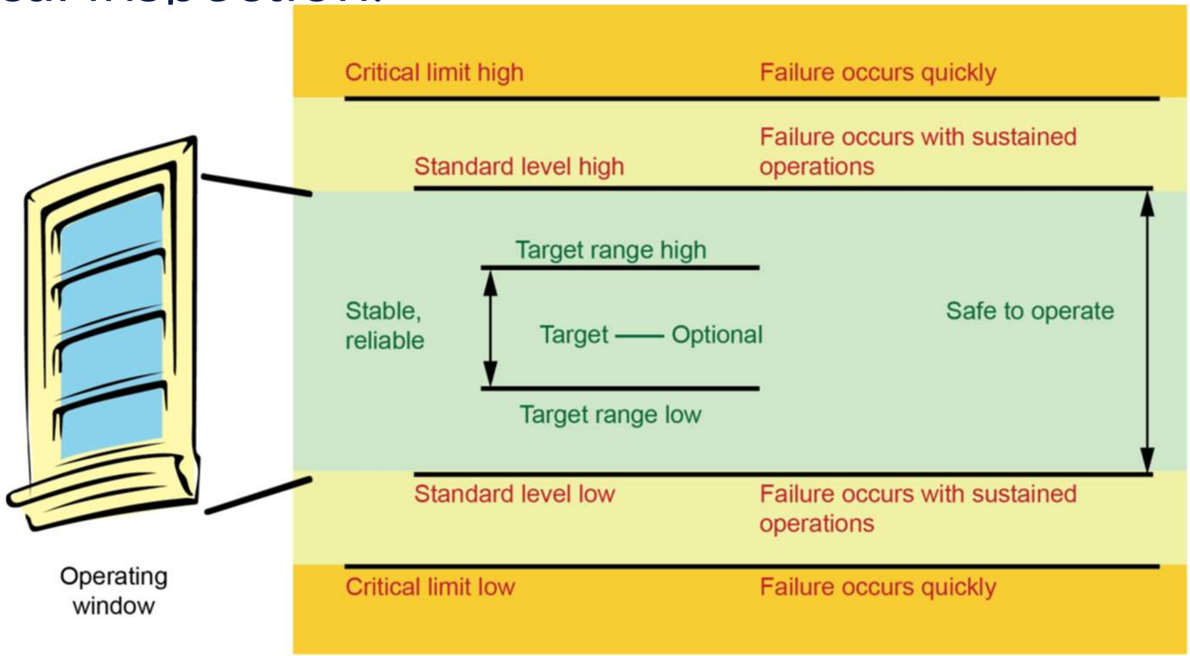
- Process unit
  - Process fluids
- Actual operating conditions
  - Temperature
  - Pressure
- Materials
  - Corrosion materials diagram
- Corrosion and damage concerns
  - Damage mechanisms
  - Injection、Mix point、Deadlegs
  - Alloy spec. break and bi-metallic welds



Ref. Development of Corrosion Control Document Database System in Crude Distillation Unit

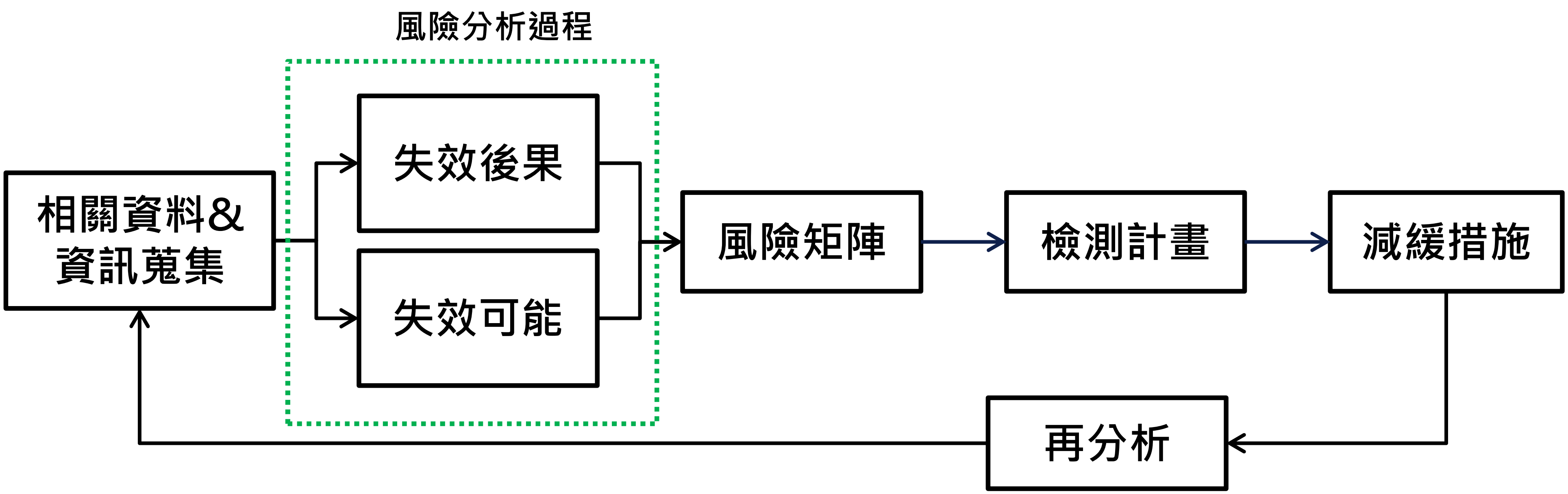
Integrity Operating Windows

- Established limits for process variables (parameters) that can affect the integrity of the equipment if the process operation deviates from the established limits for a predetermined length of time (includes Critical, Standard and Informational IOWs).
- Monitoring the IOWs can be a more effective corrosion management strategy for a non-rate based failure mechanism than performing physical inspection.



Damage Mechanism and RBI

RBI Process

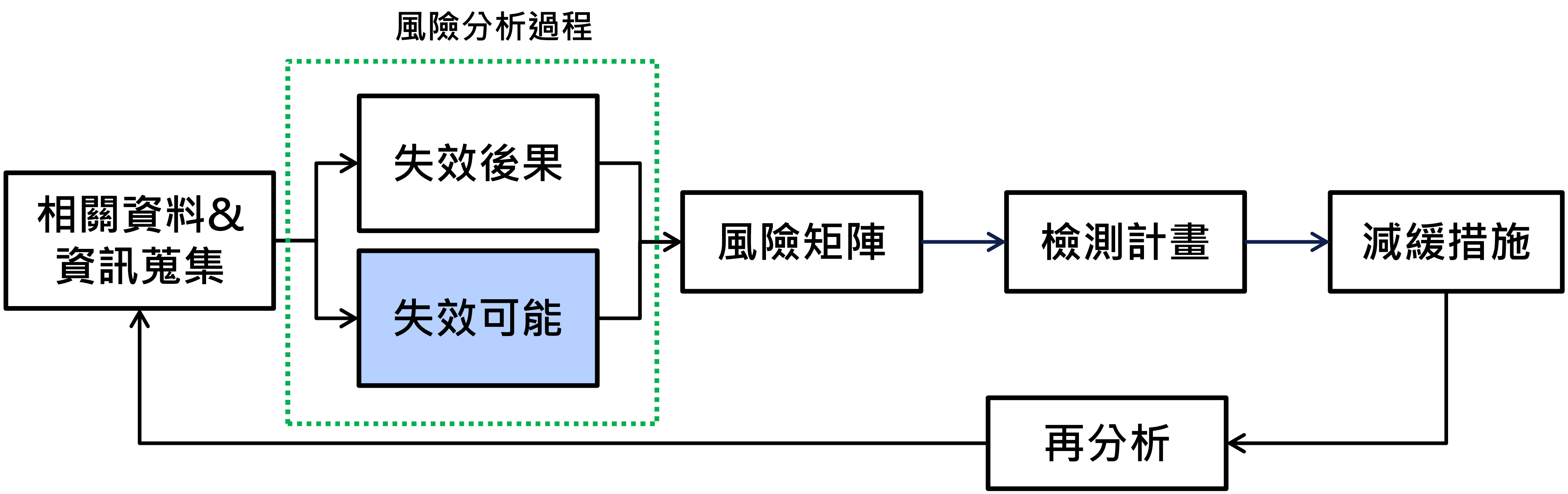


a) identification of existing damage or deterioration and anticipated rates of degradation.
b) identification of future damage mechanism susceptibilities.
c) development and maintenance of inspection and monitoring strategies, programs, and plans (e.g per API 510, API 570, and API 653),
d) implementation of Risk-Based Inspection (RBI) programs

- API RP 571 Sec.1

Damage Mechanism = Failure Mode (Probability of Failure)

DM and RBI Process



Directly influence probability of failure

- ✓ Damage mechanisms
- ✓ Corrosion rate
- ✓ Damage potentials

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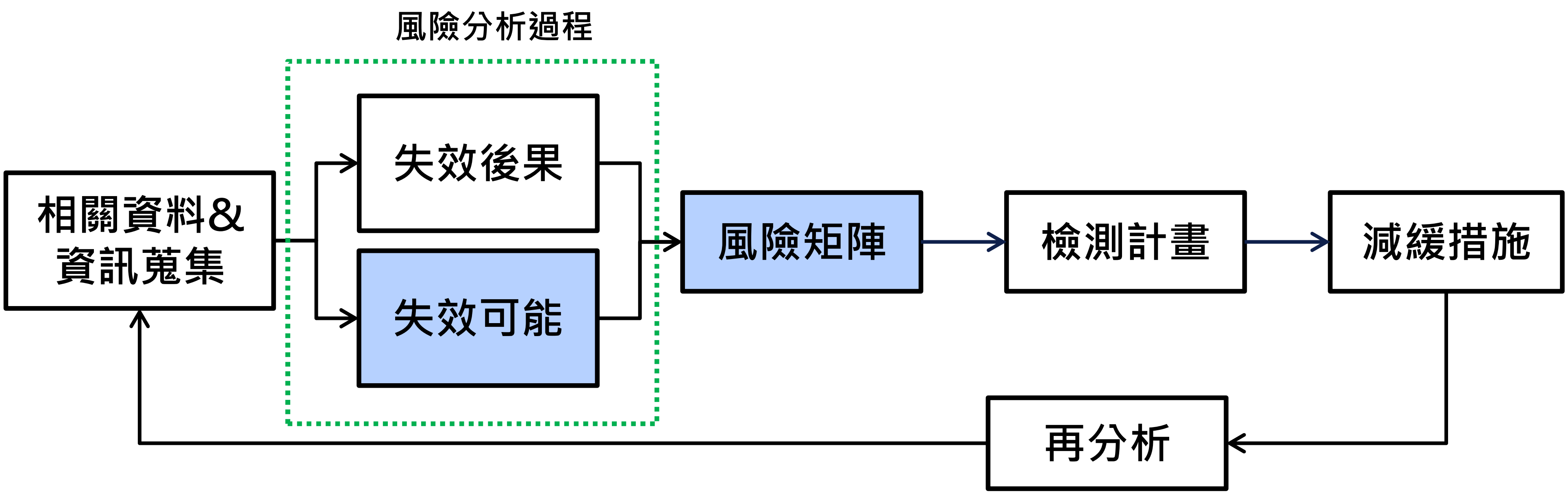
DM and RBI Process



Directly influence probability of failure

- ✓ Damage mechanisms
- ✓ Corrosion rate
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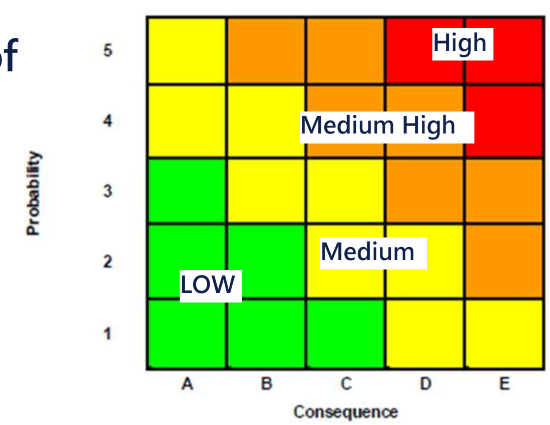

Risk = Probability X Consequence

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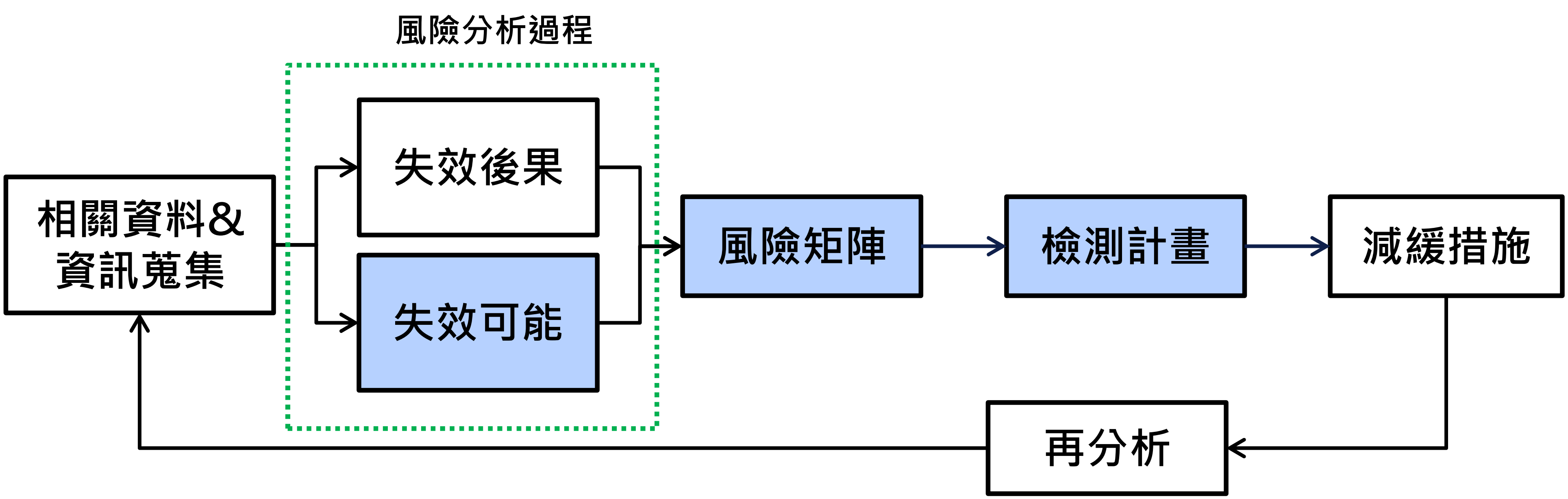
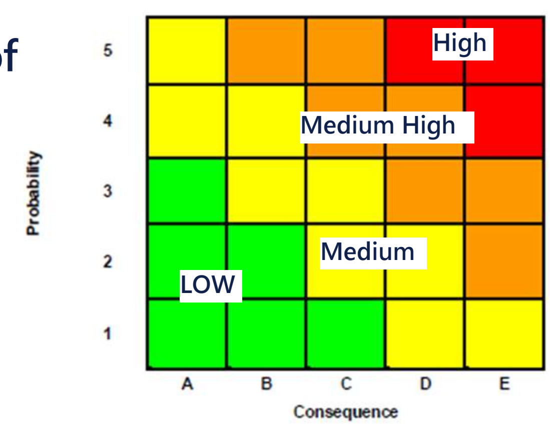
DM and RBI Process



Directly influence probability of failure

- ✓ Damage mechanisms
- ✓ Corrosion rate
- ✓ Damage potentials



Risk = Probability X Consequence

確定檢查方法

Damage Mechanism	Inspection Method
Sulfidation Corrosion Under Insulation (CUI) Atmospheric Corrosion Soil Corrosion Ammonia Stress Corrosion Cracking	Visual Test Liquid penetrant Magnetic Particle ACFM Dimensional UTM Ultrasonics Radiography Hardness test Eddy current

Performing a DM

Input

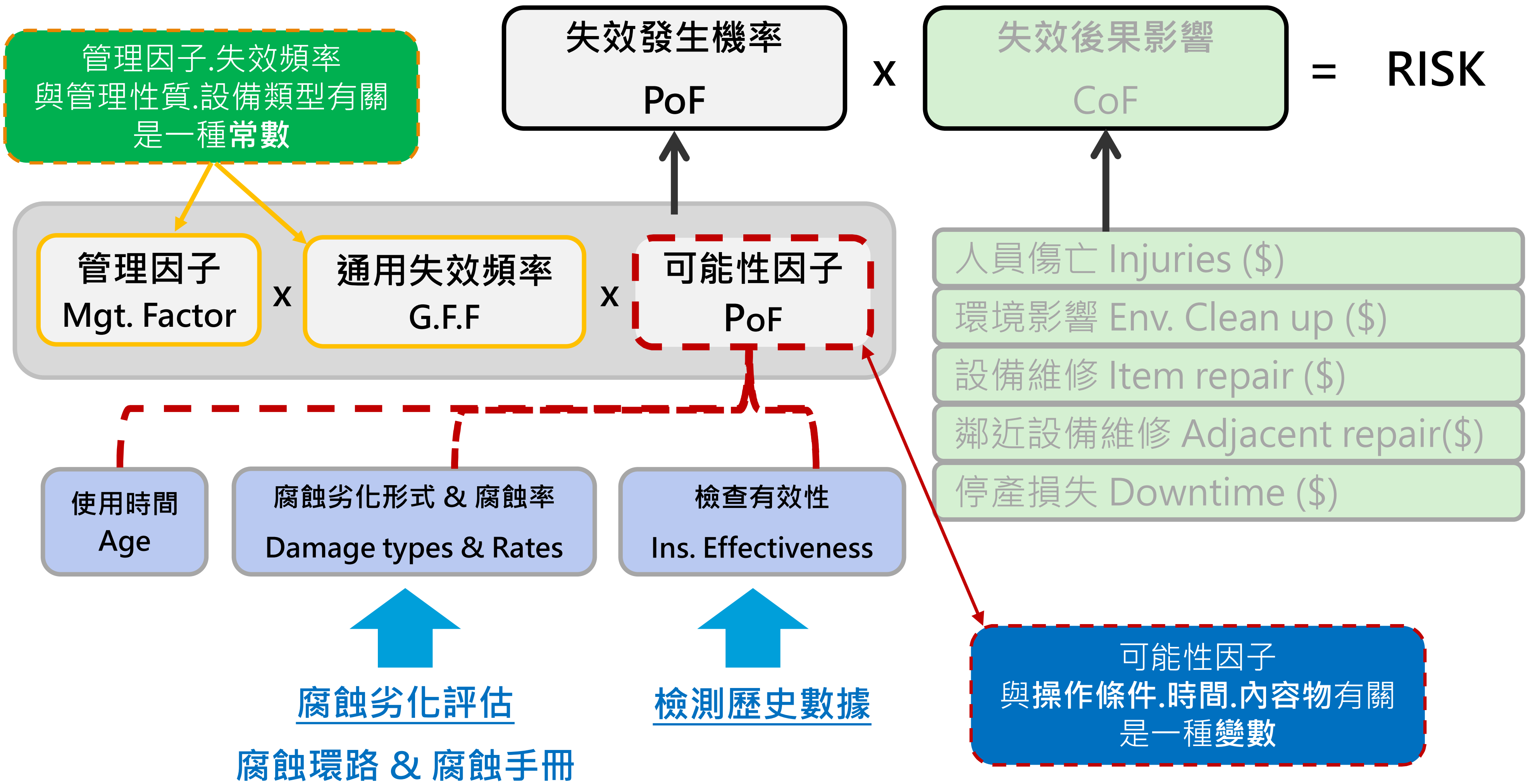
- material of construction
- design data
- Process
- Flow
- Operating conditions
- Corrosive species
- Sampling and monitoring
- Corrosion models
- Industry standards
- Unit experience
- Type of loading
- Other

Output

- ✓ Damage rate
- ✓ Corrosion rate
- ✓ Damage mechanisms
- ✓ Damage potential
- ✓ Damage type
- ✓ Mitigation recommendations
- ✓ Inspection programs

失效發生機率(PoF)計算

- 在失效可能性計算上著重在可能性因子 ➔ 會隨時間而異動



DM at API RP581

❑ API RP581 所支援的劣化損壞因子計算 (PoF)

- **Thinning**
- **SCC** (Caustic cracking, Amine cracking, Sulfide stress cracking, HIC/SOHIC-H2S, Crbonate cracking, PTA cracking, CLSCC, HSC-HF, HIC/SOHIC-HF)
- Component lining
- **External corrosion – ferritic component**
- **CUI – ferritic component**
- **External CLSCC– austenitic component**
- **External CUI CLSCC – austenitic component**
- HTHA
- Brittle facture
- Temper embrittlement
- 885 embrittlement
- Sigma phase embrittlement
- Piping mechanical fatigue

POF分析所需的基本成分數據

- Start date
- Thickness
- Corrosion allowance
- Design temperature
- Design pressure
- Operating temperature
- Operating pressure
- Design code
- Equipment type
- Component type
- Component geometry data
- Material specification
- Yield strength
- Tensile strength
- Weld joint efficiency
- Heat tracing

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確認外部腐蝕所需的數據

- Driver
  - (operating temperature、weather conditions、surface condition)
- Corrosion rate
- Coating installation date
- Coating quality
- Design
- Interface penalty
- Inspection effectiveness category
- Number of inspections
- Thickness reading
- Thickness reading date

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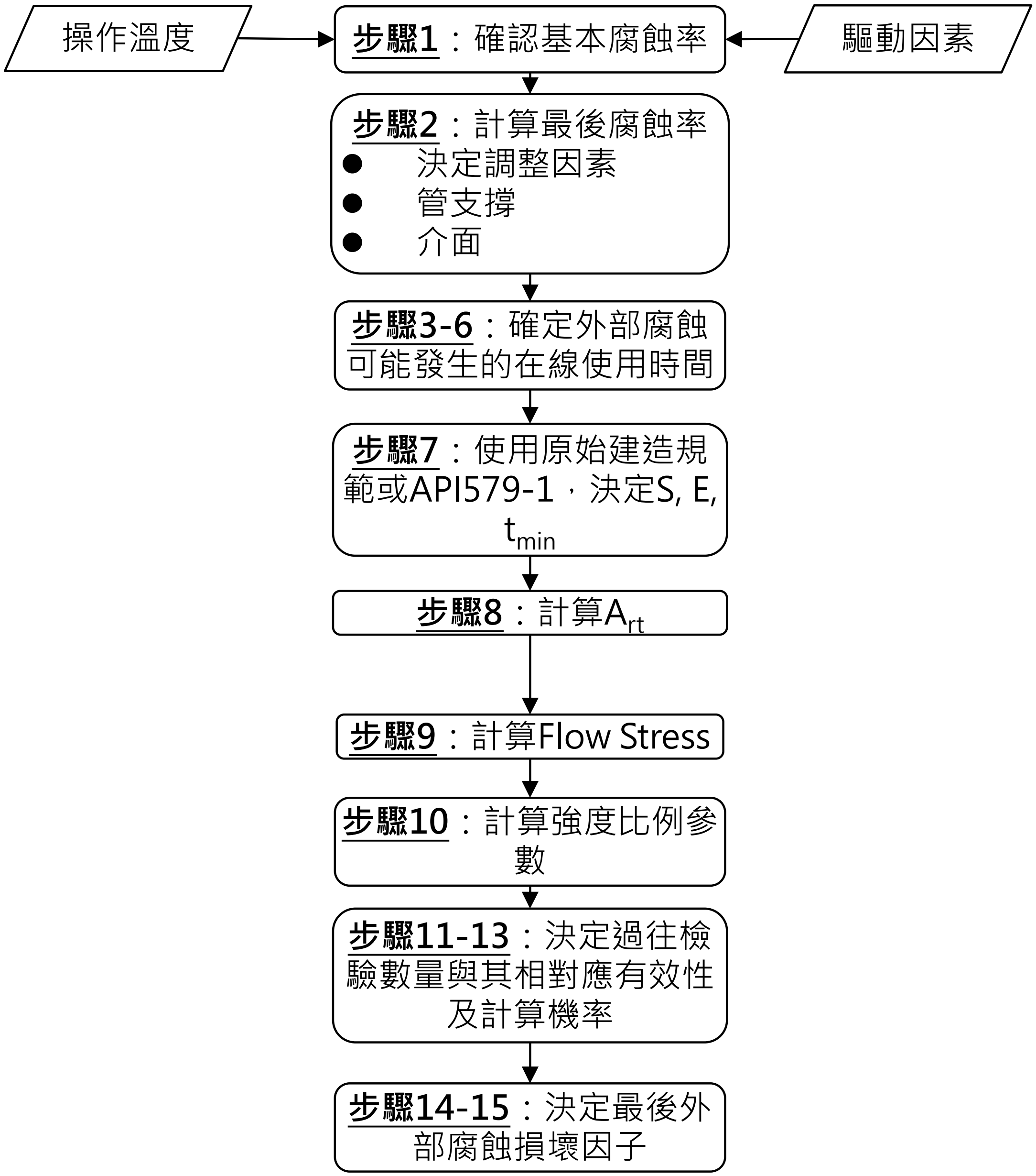
外部腐蝕評估流程


操作溫度
步驟1：確認基本腐蝕率
驅動因素
步驟2：計算最後腐蝕率
● 決定調整因素
● 管支撐
● 介面
步驟3-6：確定外部腐蝕可能發生的在線使用時間
步驟7：使用原始建造規範或API579-1，決定S, E, t_{min}
步驟8：計算A_{rt}
步驟9：計算Flow Stress
步驟10：計算強度比例參數
步驟11-13：決定過往檢驗數量與其相對應有效性及計算機率
步驟14-15：決定最後外部腐蝕損壞因子

確認CUI所需的數據

- Insulation type
- Driver
  - (operating temperature、weather conditions、surface condition)
- Corrosion rate
- Coating installation date
- Coating quality
- Equipment design/fabrication penalty
- Complexity
- Insulation condition
- Pipe support
- Inspection effectiveness category
- Number of inspections
- Thickness reading
- Thickness reading date

Table 16.2M—Corrosion Rates for Calculation of the DF—CUI

Operating Temperature (°C)	Corrosion Rate as a Function of Driver [1] (mm/y)			
	Severe	Moderate	Mild	Dry
−12	0	0	0	0
−8	0.076	0.025	0	0
6	0.254	0.127	0.076	0.025
32	0.254	0.127	0.076	0.025
71	0.508	0.254	0.127	0.051
107	0.254	0.127	0.025	0.025
135	0.254	0.051	0.025	0
162	0.127	0.025	0	0
176	0	0	0	0

NOTE 1 Driver is defined as the CUI condition causing the corrosion rate. See Part 2, Section 15.6.2 for explanation of drivers.

NOTE 2 Interpolation may be used for intermediate values of temperature.

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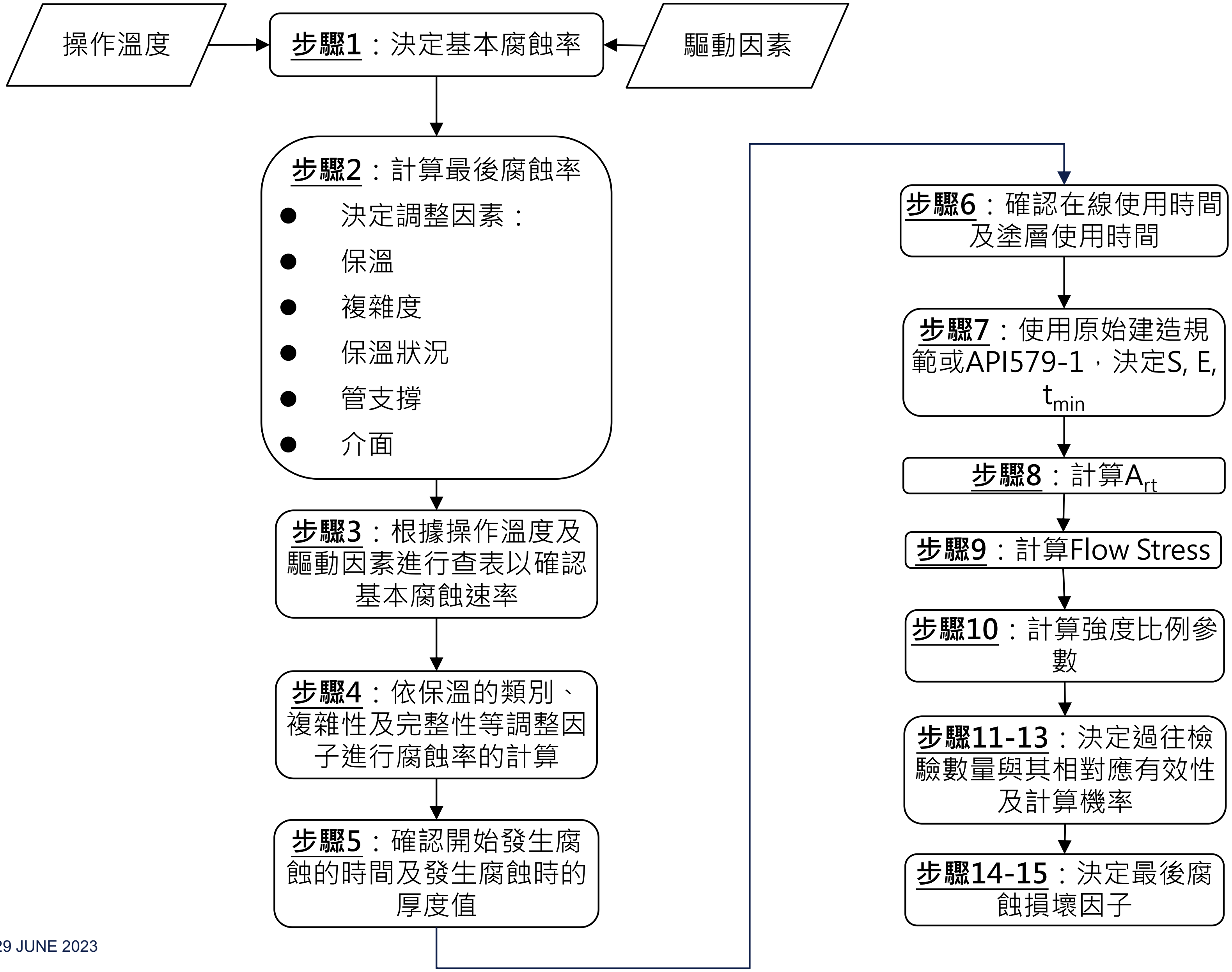
CUI評估流程


操作溫度
步驟1：決定基本腐蝕率
驅動因素
步驟2：計算最後腐蝕率
● 決定調整因素：
● 保溫
● 複雜度
● 保溫狀況
● 管支撐
● 介面
步驟3：根據操作溫度及驅動因素進行查表以確認基本腐蝕速率
步驟4：依保溫的類別、複雜性及完整性等調整因子進行腐蝕率的計算
步驟5：確認開始發生腐蝕的時間及發生腐蝕時的厚度值
步驟6：確認在線使用時間及塗層使用時間
步驟7：使用原始建造規範或API579-1，決定S, E, t_{min}
步驟8：計算A_{rt}
步驟9：計算Flow Stress
步驟10：計算強度比例參數
步驟11-13：決定過往檢驗數量與其相對應有效性及計算機率
步驟14-15：決定最後腐蝕損壞因子

CUI CISCC評估所需的數據

- Driver
  - (operating temperature、weather conditions、surface condition)
- Crack severity
- Date
- Coating quality
- Coating date
- Inspection effectiveness category
- Insulation condition
- Complexity
- Number of inspections
- Operating Temperature

Table 18.2—SCC Susceptibility—CUI CISCC

Operating Temperature		SCC Susceptibility as a Function of Driver *			
°C	°F	Severe	Moderate	Mild	Dry
<49	<120	None	None	None	None
49 to 93	120 to 200	High	High	Medium	Low
93 to 149	200 to 300	High	Medium	Low	None
>149	>300	None	None	None	None

* Driver is defined as the atmospheric condition causing the SCC.

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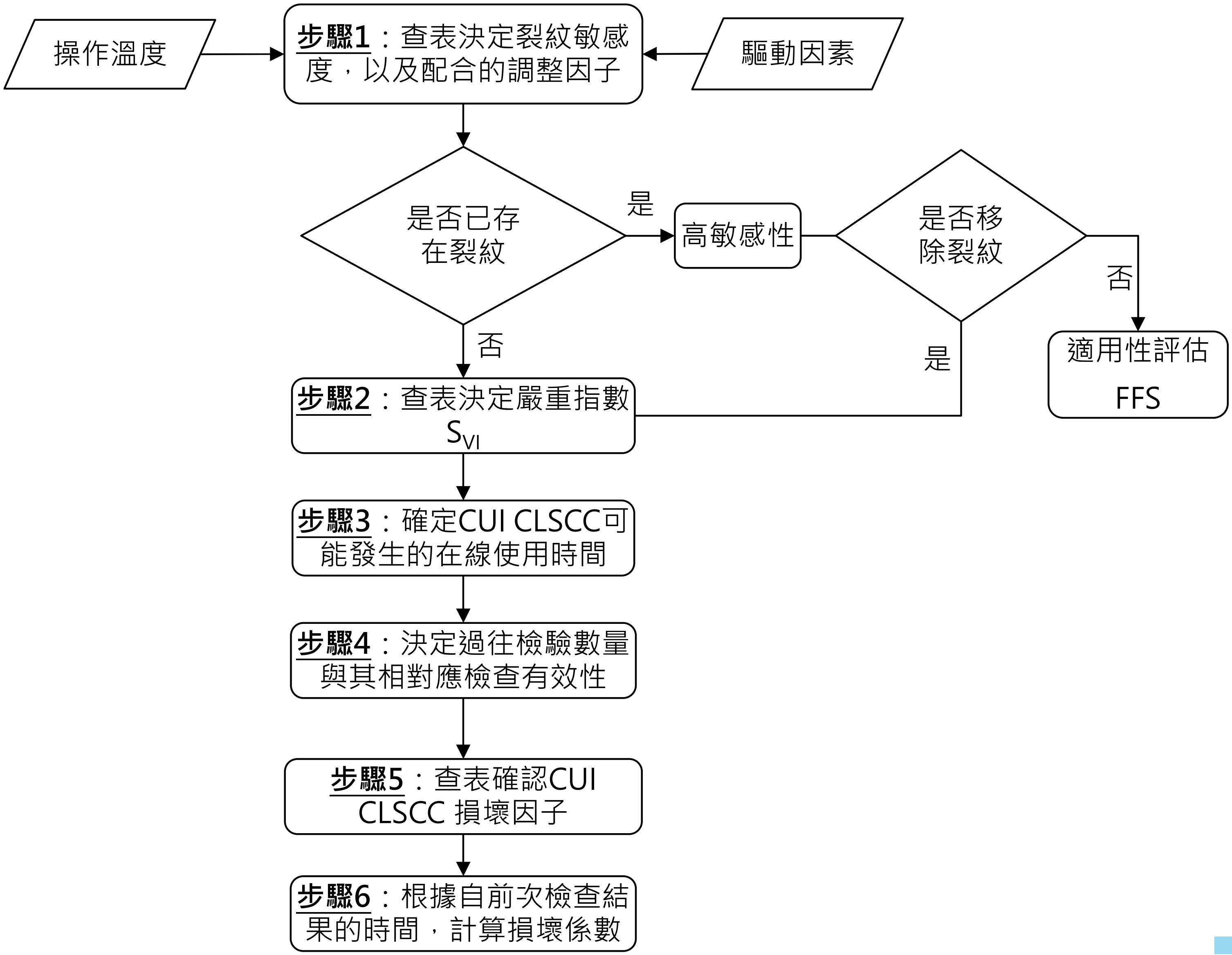
CUI CISCC評估流程



確認HTHA所需的數據

- Material of construction
  - e.g. carbon steel、 C-½ Mo、2 ¼ Cr-1 Mo
- Hydrogen partial pressure, (psia)
- Temperature

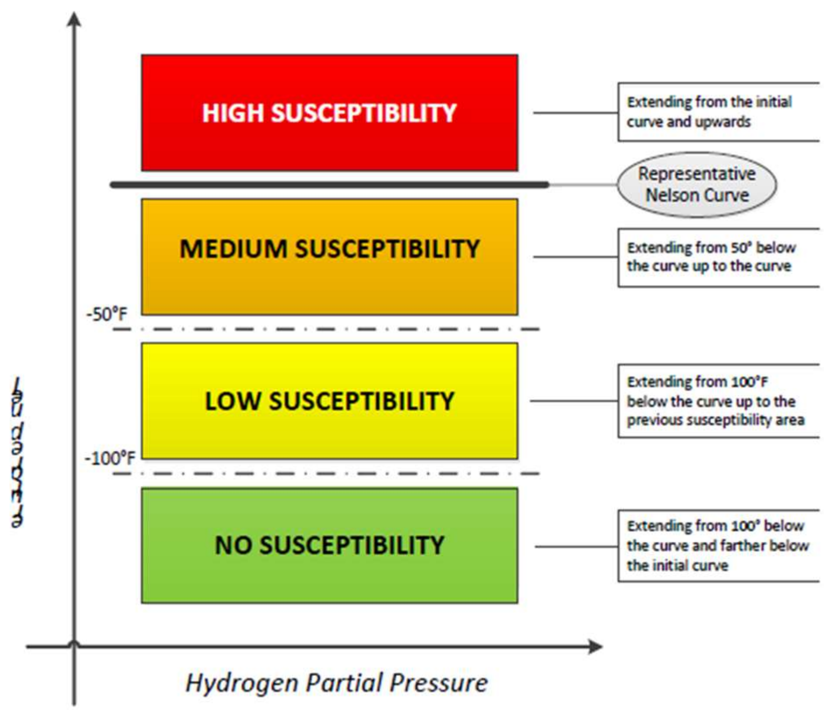
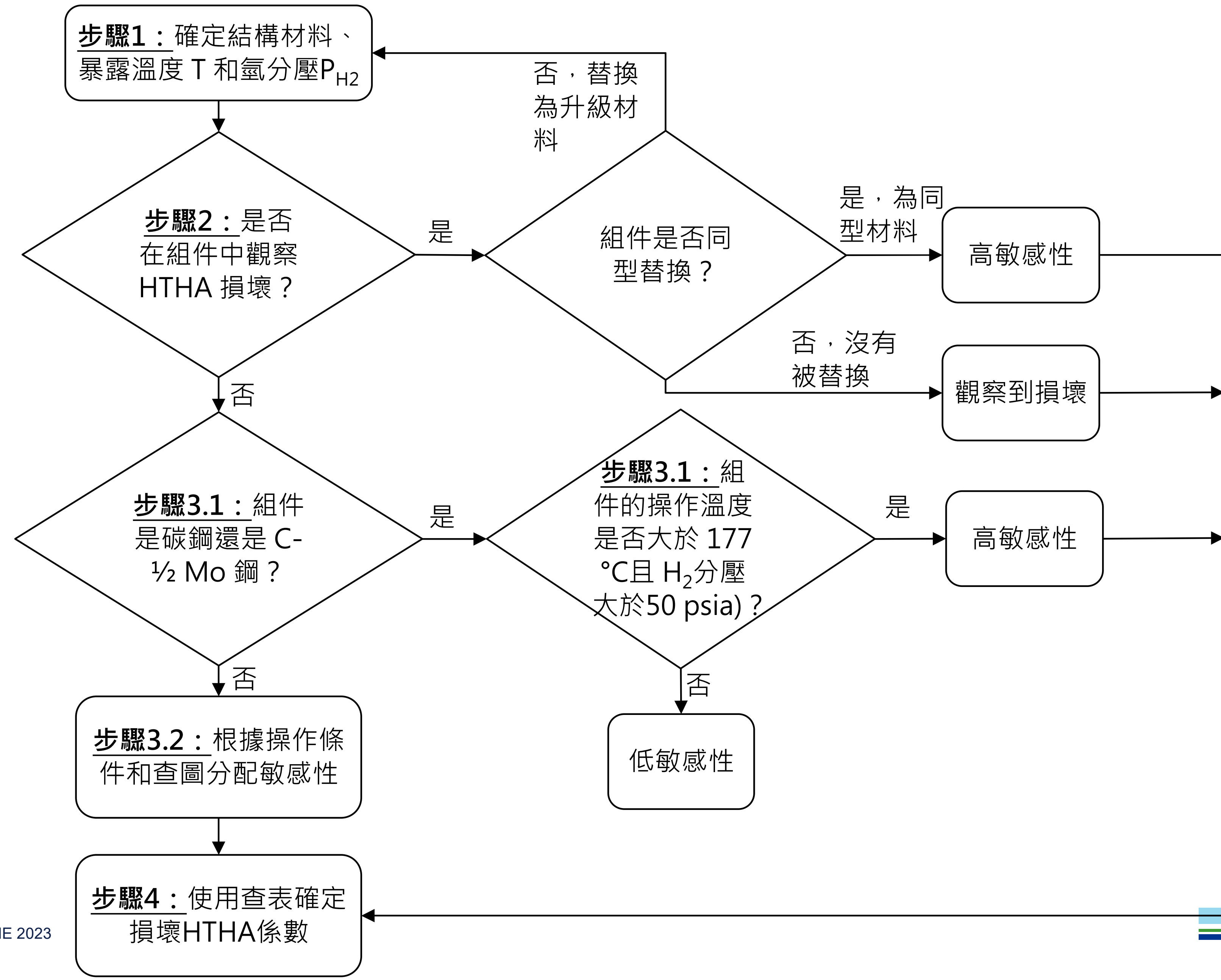


Figure 19.1—Example of HTHA Susceptibility Rankings for Cr-Mo Low Alloy Steels

HTHA評估流程



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Corrosion Circuit

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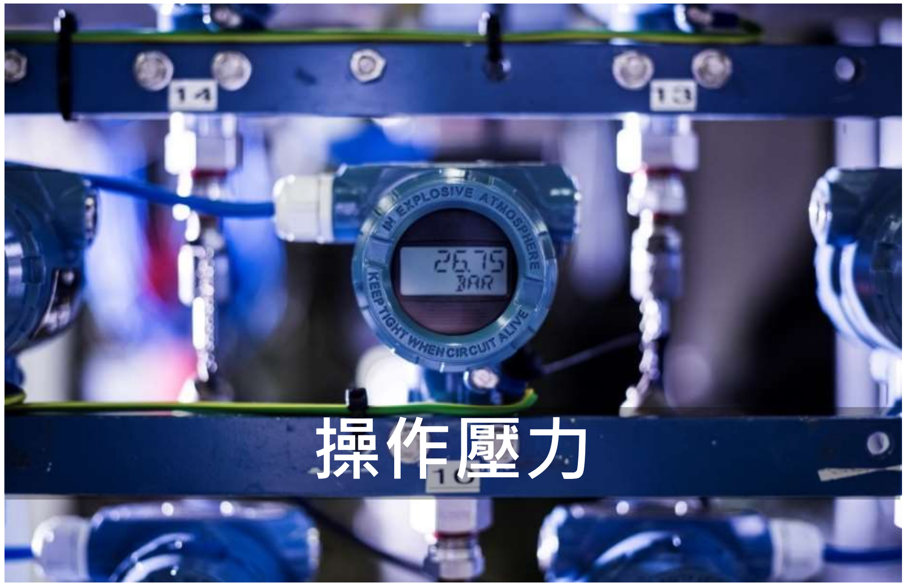
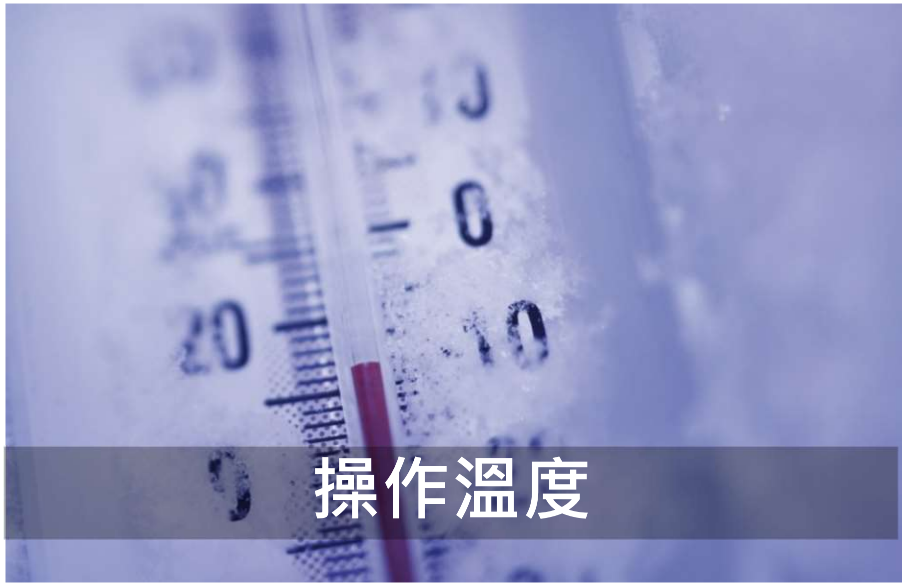
內容物成分(腐蝕介質)


操作壓力


操作溫度


材料

定義腐蝕迴路 – 其它腐蝕特徵

- 內容物流速
  - 腐蝕型態（均勻腐蝕、局部腐蝕）
  - 沖蝕、沉積腐蝕
- 非經常性操作管線、設備
- 管線注入點
- 是否有保溫包覆 / 塗層 / 伴熱
- 配合特定的腐蝕劣化機制所需的取樣資訊
  - 特定內容物的濃度
  - pH值

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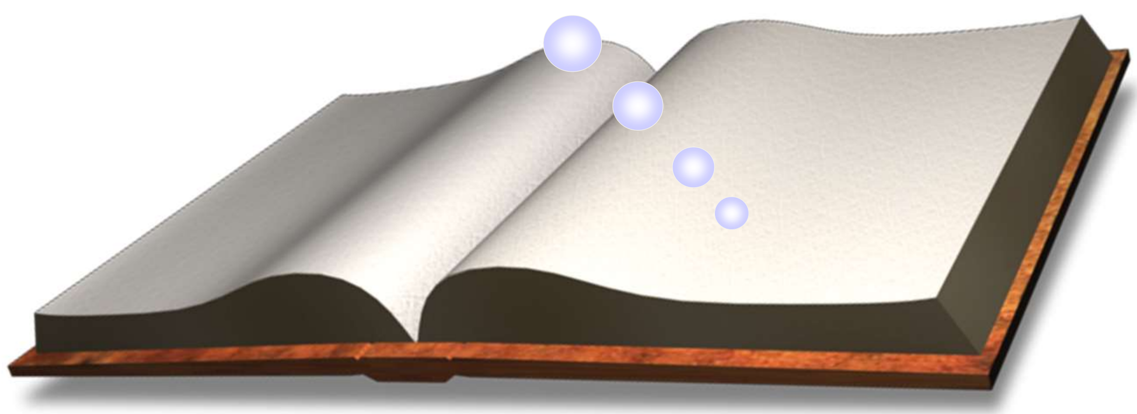
訂定腐蝕環路的外部參考文件

- API RP571
- API RP580 Risk-Based Inspection
- API RP581 Base Resource Documentation for Risk Based Inspection
- 其他如DNV GL RP、NACE papers



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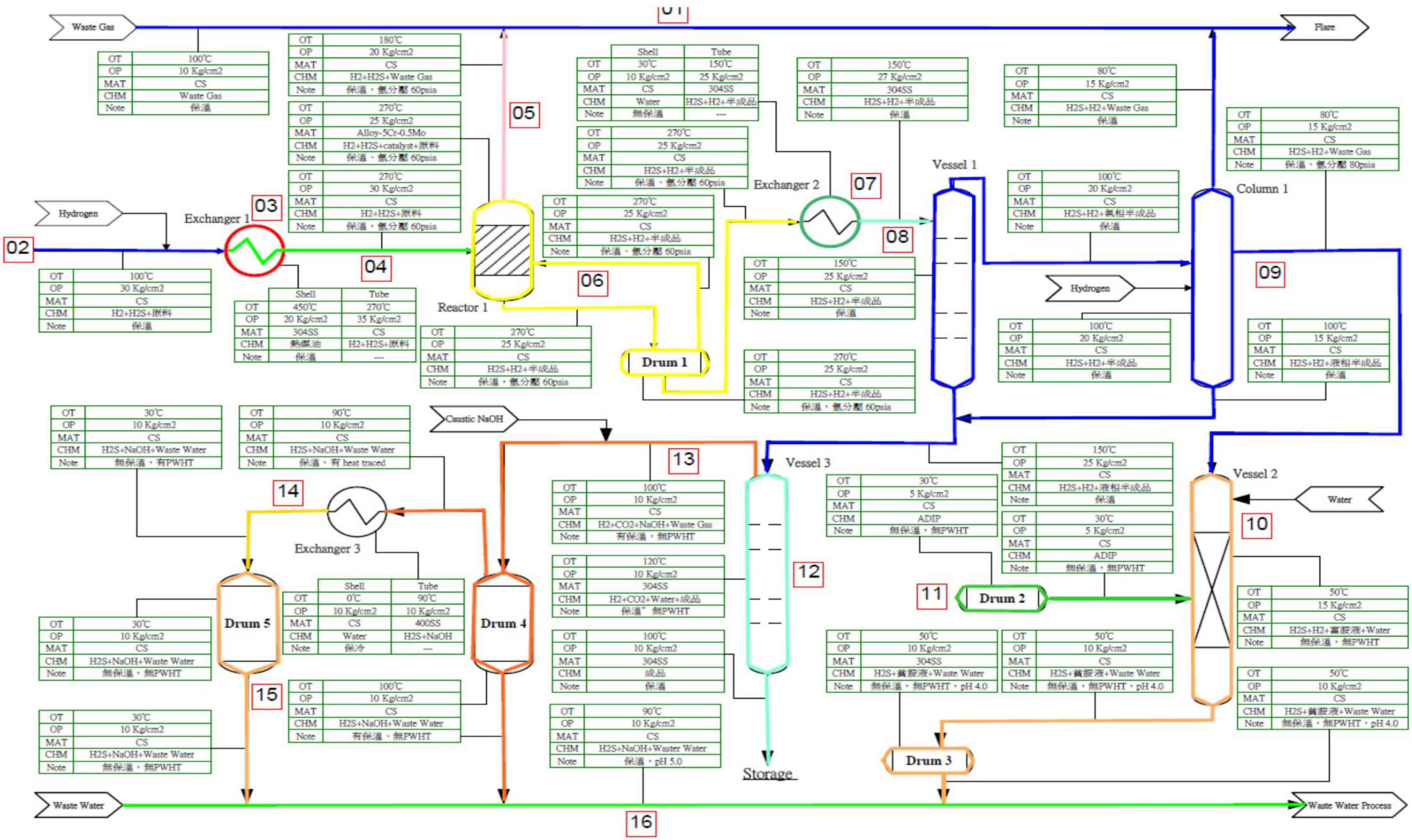
腐蝕迴路訂定範例



Waste Gas
Flare
Hydrogen
Exchanger 1
Reactor 1
Drum 1
Exchanger 2
Vessel 1
Column 1
Caustic NaOH
Exchanger 3
Drum 5
Drum 4
Vessel 3
Storage
Drum 2
Drum 3
Vessel 2
Water
Waste Water
Waste Water Process
02
03
04
05
06
07
08
09
10
11
12
13
14
15
16

定義腐蝕迴路 – 基本概念

- 材質相同
- 內容物相同
- 相近的操作環境
- 相同的腐蝕機制

STEP 1 - 資料收集

項目	所需資料
1	Process Operation Manual /Process Description
2	Equipment list / Piping list
3	Design Data Sheet
4	P&ID/PFD
5	Piping Class
6	Material Balance
7	Equipment / Piping MOC
8	ITPM
9	Equipment / Piping UTM & CMLs
10	Plant PDMS(3D)、ISO

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Step 2 – 判定腐蝕機制

- 同一腐蝕迴路下，原則上應有相同的腐蝕機制及相近的腐蝕率
- 腐蝕型態判斷
  - 均勻腐蝕
  - 局部腐蝕
  - 裂紋
  - 複合式腐蝕型態
- 腐蝕率的判定須嚴謹考量：
  - 腐蝕專家建議（包含API RP581）
  - 檢查記錄數據
  - 業界相同製程的腐蝕率數據
  - 合理的保守估計

Step 2 – 判定腐蝕機制(續)

- 基於以下因素的判斷：
  - 對於製程的了解
  - 對於操作條件和流體特性的知識
  - 對於設備/管線材質的知識
  - 對於劣化/腐蝕機制的知識
- 綜合以上的資訊，再和現場人員做最後的確認

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依據 API RP581 來判斷腐蝕機制

- 舊版 API 581

Screening Questions	Action
1. Caustic Cracking Is the material carbon or low alloy steel? Does the environment contain caustic in any concentration?	If Yes to both, proceed to Appendix H.5.
2. Amine Cracking Is the material of construction carbon or low alloy steel? Is the equipment exposed to acid gas treating amines (MEA, DEA, DIPA, MDEA, etc.)?	If Yes to both, proceed to Appendix H.6.
3. SSC/HIC/SOHIC Is the material of construction carbon or low alloy steel? Does the environment contain water and H_2S?	If Yes to both, proceed to both Appendix H.7 and H.8.
4. Carbonate Cracking Is the material of construction carbon steel? Does the environment contain sour water at pH > 7.5?	If Yes to both, proceed to Appendix H.9.
5. Polythionic Acid Cracking (PTA) Is the material austenitic stainless steel or nickel based alloys? Is the equipment exposed to sulfur bearing compounds?	If Yes to both, proceed to Appendix H 10.
6. Chloride Stress Corrosion Cracking (ClSCC) Is the material austenitic stainless steel? Is the equipment exposed or potentially exposed to chlorides and water also considering upsets and hydrotest water remaining in equipment for and process conditions? Is the operating temperature between 100°F and 300°F? (38 & 149℃)	If Yes to all, proceed to Appendix H.11.

- 新版 API 581
  - SCC – Caustic Cracking

6.3 Screening Criteria

If the component's material of construction is carbon or low alloy steel and the process environment contains caustic in any concentration, then the component should be evaluated for susceptibility to caustic cracking.

材質是否為碳鋼或是低合金鋼？

製程中是否存在鹼性物質濃縮？

- 大致的判斷流程如下：
- 1. 是否符合篩選條件
- 2. 針對此劣化機制所需蒐集的資料
- 3. 基本的假設條件
- 4. 檢查有效性的影響
- 5. 計算損害因子 (damage factor)

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決定腐蝕率

- 同一個腐蝕環路有相似的腐蝕機制與腐蝕率
- 依據腐蝕/劣化機制來判斷腐蝕型態是局部腐蝕、均勻腐蝕、還是裂紋或是綜合效應
- 如何決定一個合理的腐蝕率？
  - 專家的意見
  - 從文獻或是其他公開文件
  - 歷史檢查記錄
  - 相似的製程記錄
- 採合理且保守的原則來推估腐蝕率

腐蝕率判斷 – 大氣腐蝕

Table 15.2M—Corrosion Rates for Calculation of the DF—External Corrosion

Operating Temperature (°C)	Corrosion Rate as a Function of Driver [1] (mm/y)			
	Severe	Moderate	Mild	Dry
−12	0	0	0	0
−8	0.076	0.025	0	0
6	0.254	0.127	0.076	0.025
32	0.254	0.127	0.076	0.025
71	0.254	0.127	0.051	0.025
107	0.051	0.025	0	0
121	0	0	0	0

NOTE 1 Driver is defined as the atmospheric condition causing the corrosion rate. See Part 2, Section 15.6.2 for explanation of drivers.

NOTE 2 Interpolation may be used for intermediate values of temperature.

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腐蝕率判斷 - CUI

Table 16.2M—Corrosion Rates for Calculation of the DF—CUI

Operating Temperature (°C)	Corrosion Rate as a Function of Driver [1] (mm/y)			
	Severe	Moderate	Mild	Dry
−12	0	0	0	0
−8	0.076	0.025	0	0
6	0.254	0.127	0.076	0.025
32	0.254	0.127	0.076	0.025
71	0.508	0.254	0.127	0.051
107	0.254	0.127	0.025	0.025
135	0.254	0.051	0.025	0
162	0.127	0.025	0	0
176	0	0	0	0

NOTE 1 Driver is defined as the CUI condition causing the corrosion rate. See Part 2, Section 15.6.2 for explanation of drivers.

NOTE 2 Interpolation may be used for intermediate values of temperature.

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判斷腐蝕型態

Table 2.B.1.2 Type of Thinning

Thinning Mechanism	Condition	Type of Thinning
Hydrochloric Acid (HCl) Corrosion	---	Local
High Temperature Sulfidic/Naphthenic Acid Corrosion	TAN ≤ 0.5	General
	TAN > 0.5	Local
High Temperature H_2S/H_2 Corrosion	---	General
Sulfuric Acid (H_2SO_4) Corrosion	Low Velocity ≤ 0.61 m/s (2 ft/s) for carbon steel, ≤ 1.22 m/s (4 ft/s) for SS, and ≤ 1.83 m/s (6 ft/s) for higher alloys	General
	High Velocity ≥ 0.61 m/s (2 ft/s) for carbon steel, ≥ 1.22 m/s (4 ft/s) for SS, and ≥ 1.83 m/s (6 ft/s) for higher alloys	Local
Hydrofluoric Acid (HF) Corrosion	---	Local
Sour Water Corrosion	Low Velocity: ≤ 6.1 m/s (20 ft/s)	General
	High Velocity: > 6.1 m/s (20 ft/s)	Local
Amine Corrosion	Low Velocity < 1.5 m/s (5 ft/s) rich amine < 6.1 m/s (20 ft/s) lean amine	General
	High Velocity > 1.5 m/s (5 ft/s) rich amine > 6.1 m/s (20 ft/s) lean amine	Local
High Temperature Oxidation	---	General
Acid Sour Water Corrosion	< 1.83 m/s (6 ft/s) ≥ 1.83 m/s (6 ft/s)	General Local
Cooling Water Corrosion	≤ 0.91 m/s (3 ft/s) 0.91-2.74 m/s (3-9 ft/s) > 2.74 m/s (9 ft/s)	Local General Local
Soil Side Corrosion	---	Local
CO_2 Corrosion	---	Local
AST Bottom	Product Side Soil Side	Local Local

API RP581 提供腐蝕型態判斷表

HCl 一律為局部腐蝕

高溫硫化物腐蝕

TAN <= 0.5, 均勻腐蝕

TAN > 0.5, 局部腐蝕

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STEP 3 – 檢視及標示腐蝕相關資訊於 PFD

- 首先一定要確認 PFD 是最新版本，如有變更能隨時更新其內容。
- 標示於 PFD 的資訊一定要清晰且可表達重要的腐蝕資訊。
- 標示的內容應該包含 (但不限於) 以下資訊：
  - 設備/管線編號
  - 內容物
  - 操作壓力
  - 操作溫度
  - 材質
  - 腐蝕率/腐蝕機制

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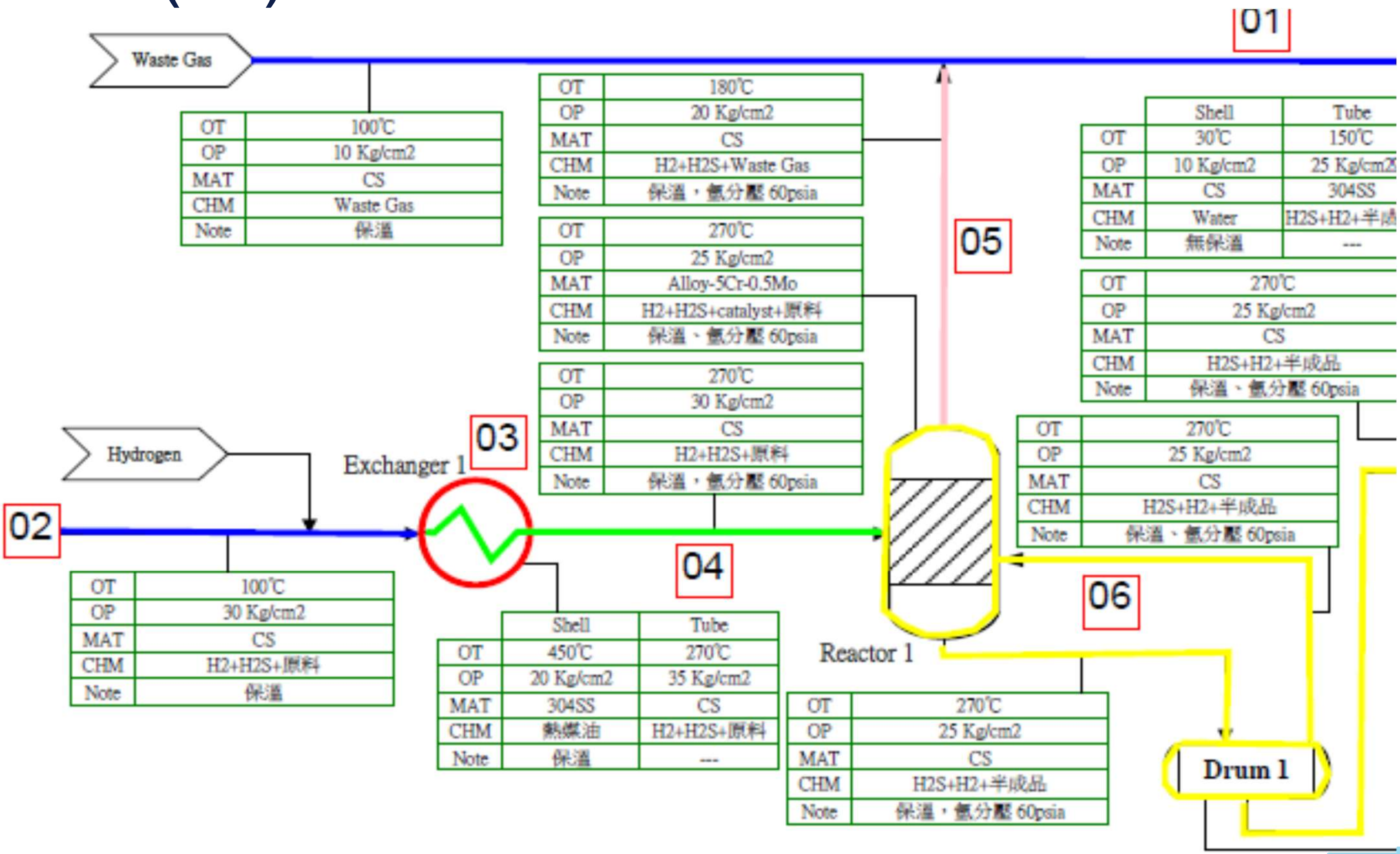
STEP 3 – 檢視及標示腐蝕相關資訊於 PFD(續)



STEP 4 – 與現場人員討論

- 執行 RBI 工作應該先從已收集到的資料進行紙上作業分析，然後與現場人員(包含製程工程師、操作人員、檢查人員、腐蝕工程師等)討論實際的操作情況與檢查/維修的歷史事件。
- 主要的討論內容包含：
  - 例行的檢查工作內容
  - 已存在的腐蝕情況
  - 易產生腐蝕的區域、設備、管線
  - 潛在影響失效後果的因素 (人員、設備、環境...)

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腐蝕手冊簡介

- 腐蝕迴路建立方法及數據來源
- 假設數據及假設方法依據
  - 新建管線長度、厚度
  - 新建管線、設備的操作溫度、壓力
- 腐蝕迴路說明
  - 製程簡述
  - 材料
  - 外部包覆
  - 操作溫度、操作壓力
  - 主要內容物
  - 內外部腐蝕因子
  - 可能劣化機制
  - 專家腐蝕率/裂紋敏感性

- 腐蝕劣化機制說明

製程簡述	V-7006-TOP → E-7017-SS	E-7017-SS → D-7006 → P-7008A/B → D-7006 inlet piping & V-7006-TOP inlet piping
材料	碳鋼	碳鋼
外部包覆	有	有
操作溫度(˚C)	100	71
操作壓力(kg/cm^2)	0.8	0.8
主要內容物	Water(0.3%) + Benzene	Water(0.3%) + Benzene
內部腐蝕因子	無	無
可能腐蝕劣化機制	包覆層下腐蝕(CUI)	包覆層下腐蝕(CUI)
專家腐蝕率/敏感性	6 mpy	10 mpy
備註		

為何要建立腐蝕手冊

- **瞭解製程特性**
  - 瞭解並整理制程主要危害/腐蝕特性
- **蒐集劣化機制資料**
  - 危害化學品清單、物流環路，評估可能發生劣化情形。
- **評估工場可能的潛在腐蝕劣化因素**
  - 腐蝕因子
  - 腐蝕機制
  - 推估的腐蝕率
- **建立腐蝕環路中的設備/管線清單**
  - 建置腐蝕環路對應之設備/管線清單
- **腐蝕手冊的資訊可提供以下資訊**
  - 檢查方法的選擇，以作為未來操作中檢修及操作人員的主要參考依據
  - 可有效的掌握未來各工場腐蝕劣化狀況
  - 在發生洩漏導致危害前予以避免之

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WHEN TRUST MATTERS

感謝聆聽

Q & A

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