WHEN TRUST MATTERS

DNV

RBI 檢查建議與檢驗有效性

SY-12-TC 量化RBI與資產完整性管理課程

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30 June 2023

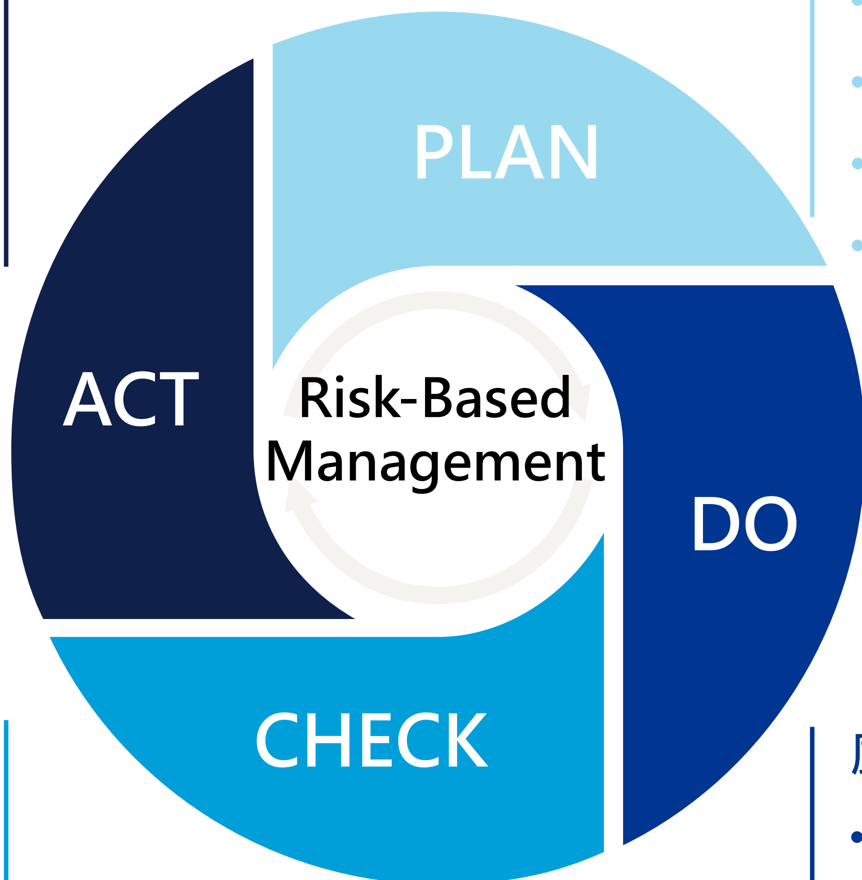
風險管理流程

持續改進Continuous Improvement

- 使用取得的成果來更新檢查策略
- 標準化和程序開發
- 經驗轉移

風險評估Risk Assessment

- 確定挑戰(Threat)
- 評估風險(Risk)
- 建立或更新風險管理計劃
- 檢查計畫



風險更新Risk Update

- 確認執行檢查的結果
- 確保並記錄風險緩解效果是否足夠

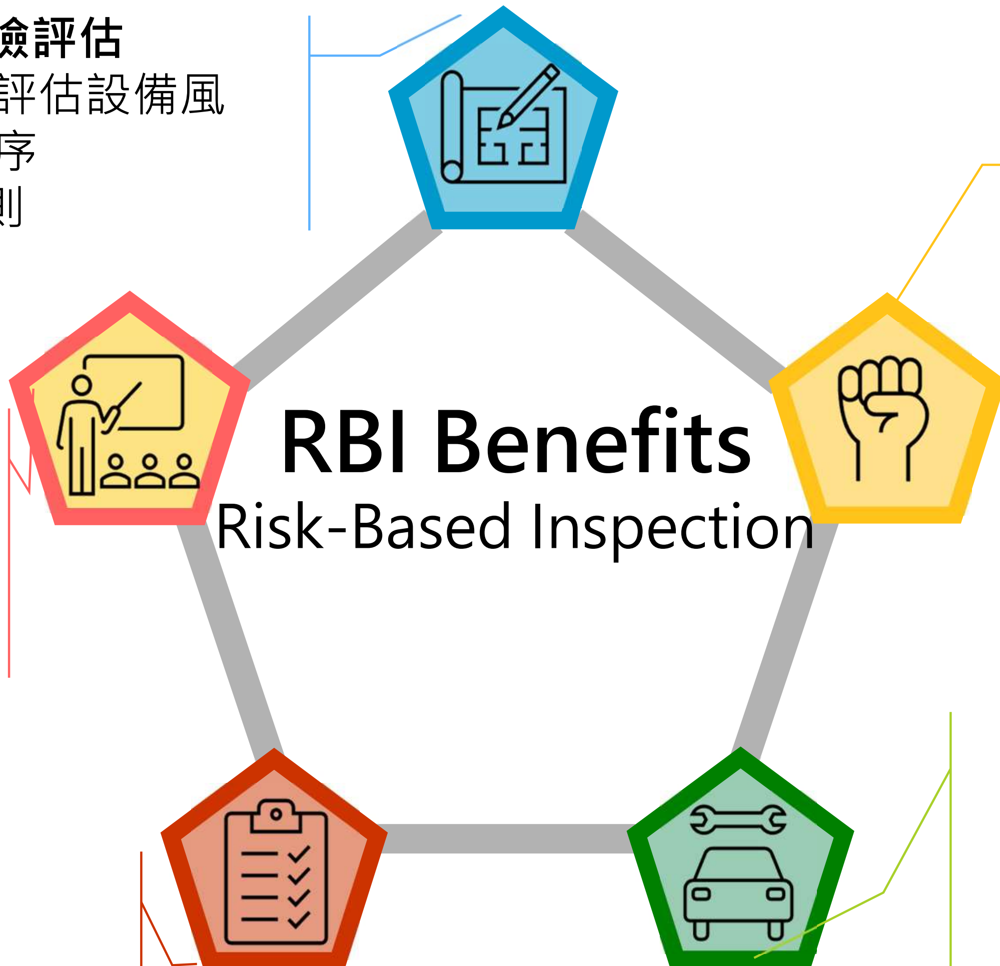
風險緩解Risk Mitigation

- 執行檢查計畫
- 執行風險緩解活動

RBI 的應用

1.進行風險評估
了解所有評估設備風
險等級排序
20/80原則

2.清楚風險驅動因素
影響風險變化的原因
(製程條件、外部環
境、設計、內容物質)



5.掌握設備風險變化
檢測計畫或其它風險減
輕措施實行後，設備的
風險變化

4.安排風險減緩方法
檢測外其他的預防措施方法
(維修、更換或提升安全防
護措施)
應變計畫

3.排定檢測計畫
檢查方法(NDT)
檢查比例
檢查時間
檢查週期

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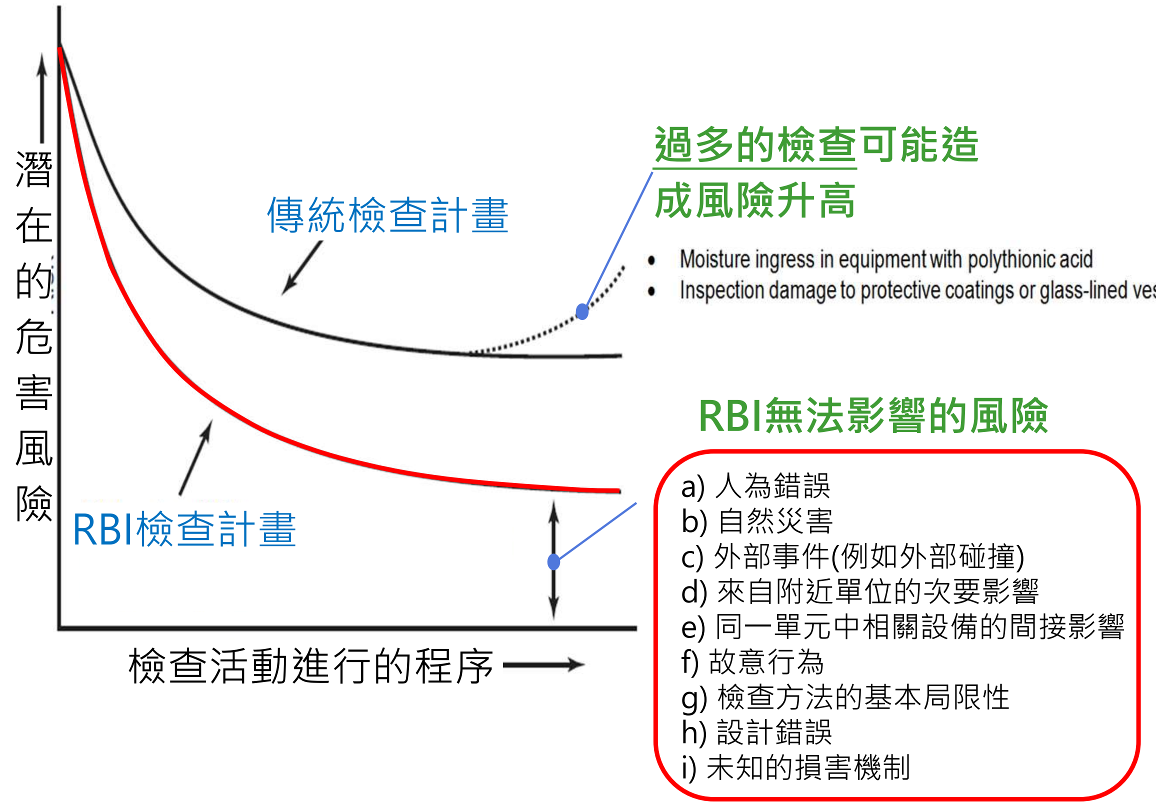
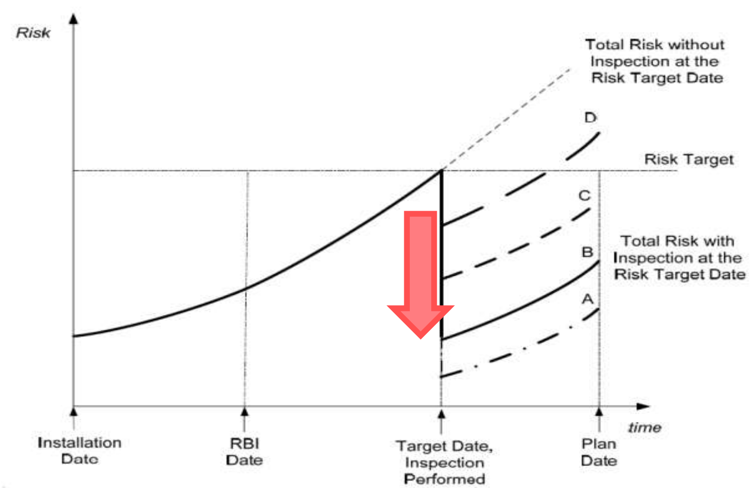
檢查計畫

- 工廠過往經驗
- 公司程序文件
- 可靠的工程實務
- 法規
- 國家標準
- 非共識文件





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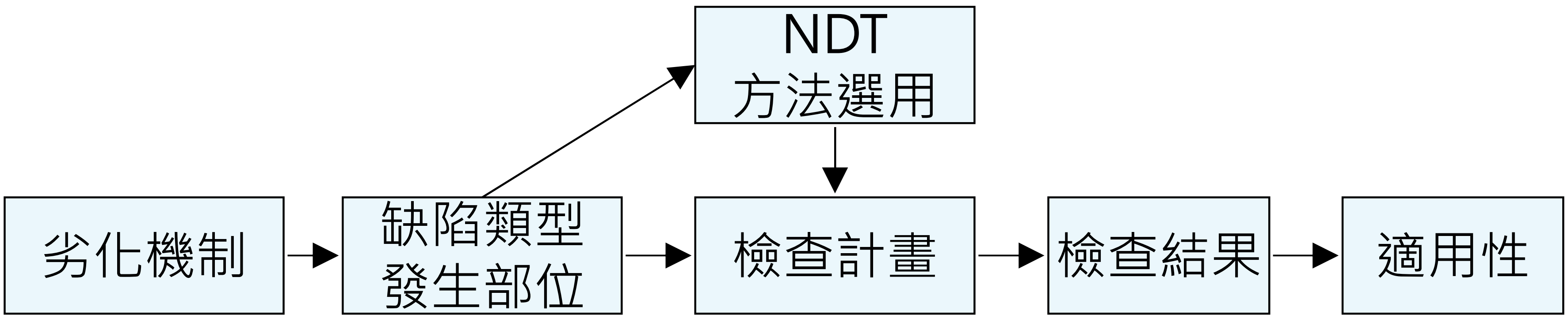
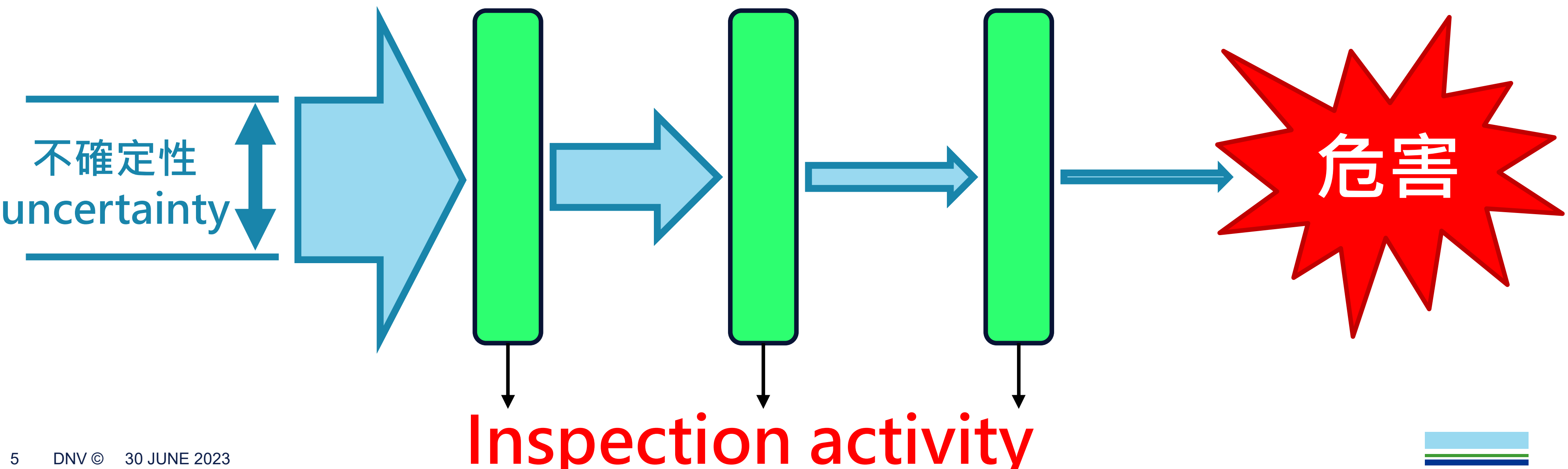
檢查重要性



- **Effective** in preventing the consequence when it functions as specified



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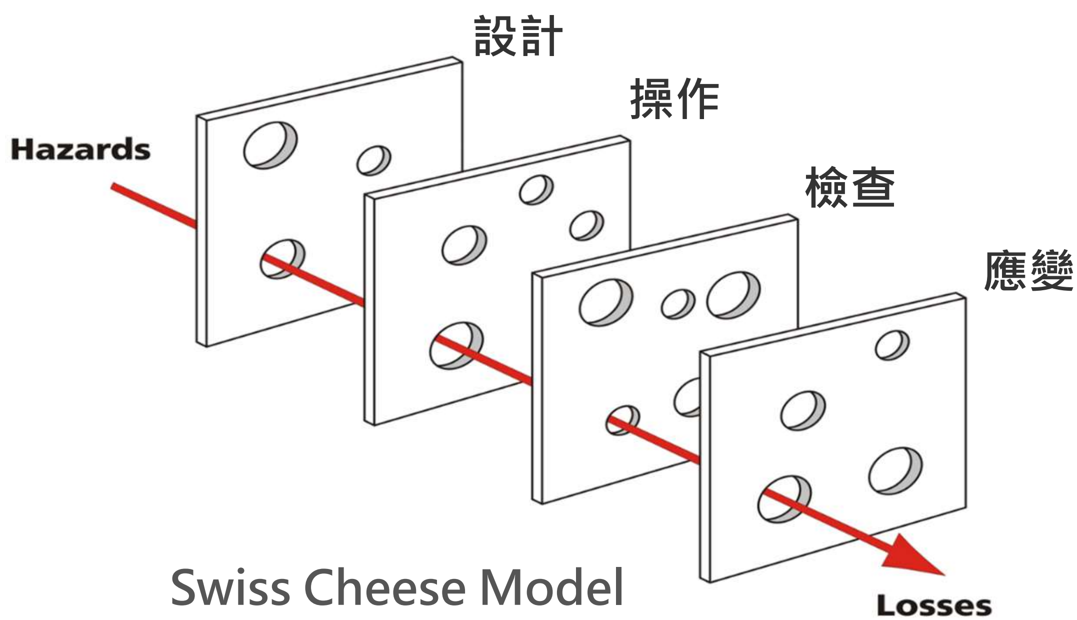
檢查有效性

- **Inspection effectiveness**

The ability of the inspection activity to reduce the uncertainty in the damage state of the equipment or component.

Inspection effectiveness is thus an integral part of a robust inspection planning methodology.

Inspection effectiveness categories are used to reduce uncertainty in the models for calculating the POF.



Swiss Cheese Model

Inspection Effectiveness

Table 2.C.2.1 – Inspection Effectiveness Categories

Inspection Effectiveness Category	Inspection Effectiveness Description	Description
A	Highly Effective	The inspection methods will correctly identify the true damage state in nearly every case (or 80-100% confidence).
B	Usually Effective	The inspection methods will correctly identify the true damage state most of the time (or 60-80% confidence).
C	Fairly Effective	The inspection methods will correctly identify the true damage state about half of the time (or 40-60% confidence).
D	Poorly Effective	The inspection methods will provide little information to correctly identify the true damage state (or 20-40% confidence).
E	Ineffective	The inspection method will provide no or almost no information that will correctly identify the true damage state and are considered ineffective for detecting the specific damage mechanism (less than 20% confidence).

Note: On an inspection effectiveness category E, the terminology of ineffective may refer to one or more of the following cases:

1. No inspection was completed.
2. The inspection was completed at less than the requirements stated above.
3. An ineffective inspection technique and/or plan was utilized.
4. An unproven inspection technique was utilized.
5. Insufficient information was available to adequately assess the effectiveness of the inspection.

Confidence
檢查結果的信心程度

技術-

- ✓ NDT技術的可靠度
- ✓ 檢查方式(Means)
- ✓ 檢查涵蓋率 (Coverage)

人因-

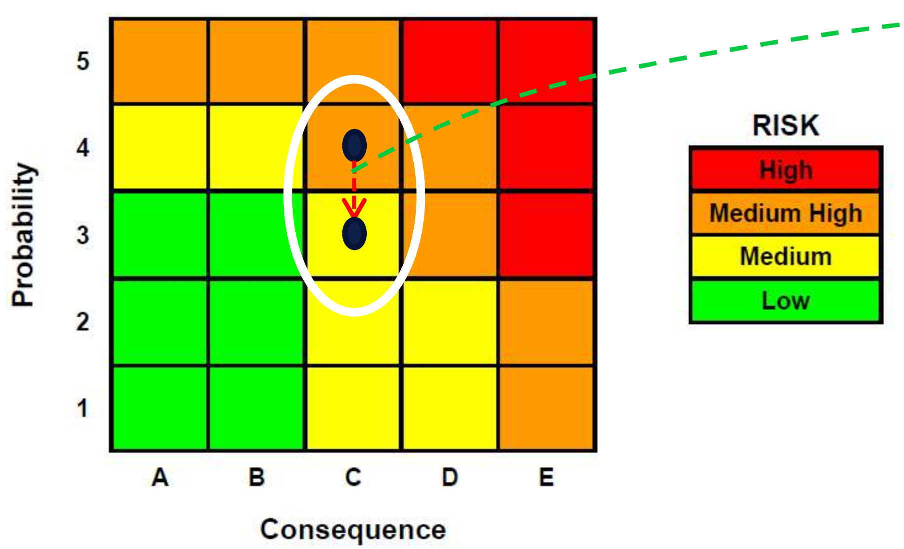
- ✓ 檢測人員影響 (Human error)
- ✓ 檢查程序的正確性
- ✓ 資格有效性

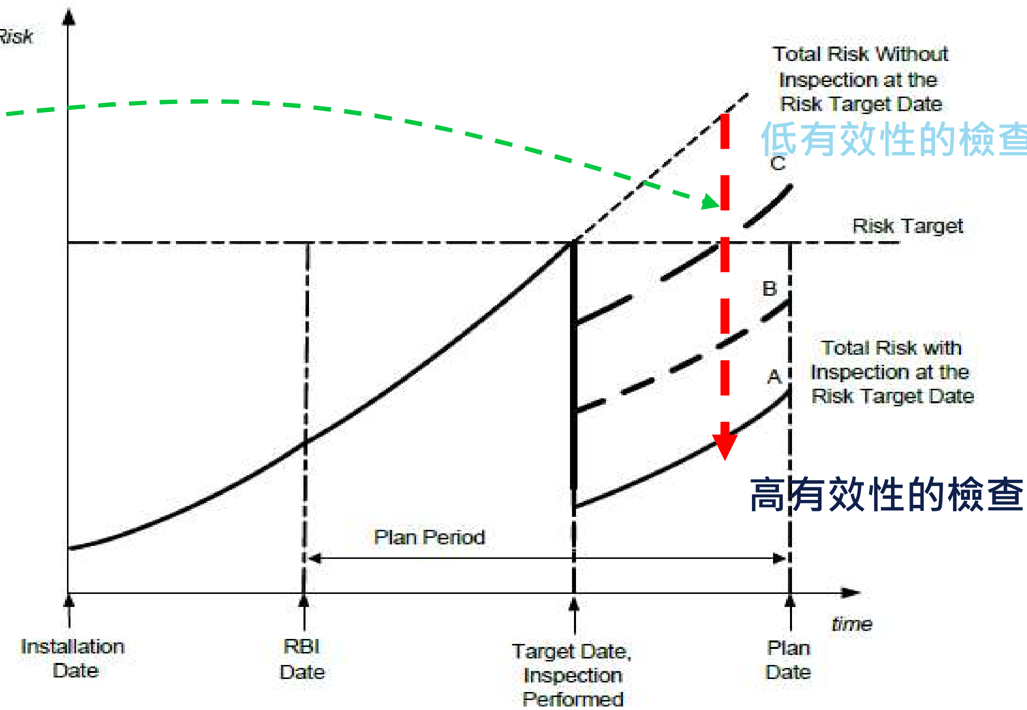
效度-

- ✓ 檢查數量是否足夠
- ✓ 檢查位置是否有代表性
- ✓ CML Optimization

檢查有效性

失效 可能性等級	損壞因子 (Damage Factor)	失效 後果等級	財務損失因子(TWD) (Financial Consequence)
1	Df ≦ 1	A	Fc ≦ 300K
2	1 ＜ Df ≦ 10	B	300K ＜ Fc ≦3M
3	10 ＜ Df ≦ 100	C	3M ＜ Fc ≦30M
4	100 ＜ Df ≦ 1,000	D	30M ＜ Fc ≦300M
5	Df > 1,000	E	Fc > 300M





◆ 透過檢查將風險逐漸提高的設備，降至低風險的區域

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Levels of Inspection Effectiveness

- **提出一個足以信任的檢測規劃，來檢測潛在的損害機制。**
  The idea is to obtain some measure of **confidence** in detecting the potential damage mechanisms by implementing the specific strategy. Note that these tables are meant as **examples only**. (**Not GUIDELINE**)

- **使用檢測有效性表格時應當審查它們並且適當地調整它們（客製），以通過降低設備狀況的不確定性（提高置信心水平）來獲得適當的降低風險**
  Each owner-operator using the tables should review them and **customize them** as appropriate to obtain the proper level of risk reduction by lowering the uncertainty (i.e., improving the confidence level) of the condition of the equipment

註 : API RP 581

Levels of Inspection Effectiveness

Table 2.C.2.1 – Inspection Effectiveness Categories

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Note: On an inspection effectiveness category E, the terminology of ineffective may refer to one or more of the following cases: 1. No inspection was completed. 2. The inspection was completed at less than the requirements stated above. 3. An ineffective inspection technique and/or plan was utilized. 4. An unproven inspection technique was utilized. 5. Insufficient information was available to adequately assess the effectiveness of the inspection.		

Equivalent relationships

- If multiple inspections have been performed, equivalent relationships are used for **SCC**, external damage [external **chloride stress corrosion cracking** (ExtClSCC), **external chloride stress corrosion cracking under insulation** (CUI ClSCC)], and **HTHA**.
- Inspections of different grades (A, B, C, and D) are approximated as equivalent inspection effectiveness in accordance with the following relationships.

a) 2 Usually Effective (B) Inspections = 1 Highly Effective (A) Inspection, or 2B = 1A.

b) 2 Fairly Effective (C) Inspections = 1 Usually Effective (B) Inspection, or 2C = 1B.

c) 2 Poorly Effective (D) Inspections = 1 Fairly Effective (C) Inspection, or 2D = 1C.

NOTE 1 Equivalent inspection values are not used for thinning and external corrosion DF calculations.

NOTE 2 The equivalent higher inspection rules shall not be applied to No Inspections (E).

Thinning vs. Inspection Effectiveness

The uncertainty in the corrosion rate varies, depending on the source and quality of the corrosion rate data. For general thinning, the reliability of the information sources used to establish a corrosion rate can be put into the following three categories:

- Low Confidence Information Sources for Corrosion Rates –Sources such as **published data**, **corrosion rate tables and expert opinion**.
- Medium Confidence Information Sources for Corrosion Rates –Sources such as **laboratory testing** with simulated process conditions or **limited in-situ corrosion coupon testing**.
- High Confidence Information Sources for Corrosion Rates –Sources such as **extensive field data from thorough inspections**.

Table 4.5—Prior Probability for Thinning Corrosion Rate

Damage State	Low Confidence Data	Medium Confidence Data	High Confidence Data
Pr_{p1}^{Thin}	0.5	0.7	0.8
Pr_{p2}^{Thin}	0.3	0.2	0.15
Pr_{p3}^{Thin}	0.2	0.1	0.05

Thinning vs. Inspection Effectiveness

Thinning DF calculations are based on the probability of three damage states being present. The three damage states are defined as:

- Damage State 1—**Damage is no worse than expected,** or a factor of **1 applied to the expected corrosion rate.**
- Damage State 2—**Damage is somewhat worse than expected**, or a factor of **2 applied to the expected corrosion rate**.
- Damage State 3—**Damage considerably worse than expected**, or a factor of **4 applied to the expected corrosion rate**.

Thinning vs. Inspection Effectiveness

$$I_1^{Thin} = Pr_{p1}^{Thin}\left(Co_{p1}^{ThinA}\right)^{N_A^{Thin}}\left(Co_{p1}^{ThinB}\right)^{N_B^{Thin}}\left(Co_{p1}^{ThinC}\right)^{N_C^{Thin}}\left(Co_{p1}^{ThinD}\right)^{N_D^{Thin}}$$

$$I_2^{Thin} = Pr_{p2}^{Thin}\left(Co_{p2}^{ThinA}\right)^{N_A^{Thin}}\left(Co_{p2}^{ThinB}\right)^{N_B^{Thin}}\left(Co_{p2}^{ThinC}\right)^{N_C^{Thin}}\left(Co_{p2}^{ThinD}\right)^{N_D^{Thin}}$$

$$I_3^{Thin} = Pr_{p3}^{Thin}\left(Co_{p3}^{ThinA}\right)^{N_A^{Thin}}\left(Co_{p3}^{ThinB}\right)^{N_B^{Thin}}\left(Co_{p3}^{ThinC}\right)^{N_C^{Thin}}\left(Co_{p3}^{ThinD}\right)^{N_D^{Thin}}$$

$$Po_{p1}^{Thin} = \frac{I_1^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

$$Po_{p2}^{Thin} = \frac{I_2^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

$$Po_{p3}^{Thin} = \frac{I_3^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

Table 4.6—Conditional Probability for Inspection Effectiveness

Conditional Probability of Inspection	E—None or Ineffective	D—Poorly Effective	C—Fairly Effective	B—Usually Effective	A—Highly Effective
Co_{p1}^{Thin}	0.33	0.4	0.5	0.7	0.9
Co_{p2}^{Thin}	0.33	0.33	0.3	0.2	0.09
Co_{p3}^{Thin}	0.33	0.27	0.2	0.1	0.01

LoIE Example for General Thinning

Inspection Category	Inspection Effectiveness Category	Intrusive Inspection Example	Non-intrusive Inspection Example
A	Highly Effective	For the total surface area: >50 % visual examination (partial internals removed) **AND** >50 % of the spot ultrasonic thickness measurements	For the total surface area: 100 % UT/RT of CMLs **OR** For selected areas: 10 % UT scanning **OR** 10 % profile radiography
B	Usually Effective	For the total surface area: >25 % visual examination **AND** >25 % of the spot ultrasonic thickness measurements	For the total surface area: >75 % spot UT **OR** >5 % UT scanning, automated or manual **OR** >5 % profile radiography of the selected area(s)
C	Fairly Effective	For the total surface area: >5 % visual examination **AND** >5 % of the spot ultrasonic thickness measurements	For the total surface area: >50 % spot UT or random UT scans (automated or manual) **OR** random profile radiography of the selected area(s)
D	Poorly Effective	For the total surface area: <5 % visual examination without thickness measurements	For the total surface area: >25 % spot UT
E	Ineffective	Ineffective inspection technique/plan was utilized	Ineffective inspection technique/plan was utilized

LoIE Example for Amine Cracking

Inspection Category	Inspection Effectiveness Category	Intrusive Inspection Example	Non-intrusive Inspection Example
A	Highly Effective	For the total weld area: 100 % WFMT/ACFM with UT follow-up of relevant indications	For the total weld area: 100 % automated or manual ultrasonic scanning
B	Usually Effective	For selected welds/weld area: >75 % WFMT/ACFM with UT follow-up of all relevant indications	For selected welds/weld area: >75 % automated or manual ultrasonic scanning OR AE testing with 100 % follow-up of relevant indications
C	Fairly Effective	For selected welds/weld area: >35 % WFMT/ACFM with UT follow-up of all relevant indications	For selected welds/weld area: >35 % automated or manual ultrasonic scanning OR >35 % radiographic testing
D	Poorly Effective	For selected welds/weld area: >10 % WFMT/ACFM with UT follow-up of all relevant indications	For selected welds/weld area: >10 % automated or manual ultrasonic scanning OR >10 % radiographic testing
E	Ineffective	Ineffective inspection technique/plan was utilized	Ineffective inspection technique/plan was utilized

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LoIE Example for CISCC

Inspection Category	Inspection Effectiveness Category	Intrusive Inspection Example	Non-intrusive Inspection Example
A	Highly Effective	For the total surface area: 100 % dye penetrant or eddy current test with UT follow-up of relevant indications	No inspection techniques are yet available to meet the requirements for an "A" level inspection
B	Usually Effective	For selected areas: >65 % dye penetrant or eddy current testing with UT follow-up of all relevant indications	For selected areas: 100 % automated or manual ultrasonic scanning OR AE testing with 100 % follow-up of relevant indications
C	Fairly Effective	For selected areas: >35 % dye penetrant or eddy current testing with UT follow-up of all relevant indications	For selected areas: >65 % automated or manual ultrasonic scanning OR >65 % radiographic testing
D	Poorly Effective	For selected areas: >10 % dye penetrant or eddy current testing with UT follow-up of all relevant indications	For selected areas: >35 % automated or manual ultrasonic scanning OR >35 % radiographic testing
E	Ineffective	Ineffective inspection technique/plan was utilized	Ineffective inspection technique/plan was utilized

LoIE Example for External Corrosion

Inspection Category	Inspection Effectiveness Category	Inspection Example
A	Highly Effective	Visual inspection of >95 % of the exposed surface area with follow-up by UT, RT, or pit gauge as required
B	Usually Effective	Visual inspection of >60 % of the exposed surface area with follow-up by UT, RT, or pit gauge as required
C	Fairly Effective	Visual inspection of >30 % of the exposed surface area with follow-up by UT, RT, or pit gauge as required
D	Poorly Effective	Visual inspection of >5 % of the exposed surface area with follow-up by UT, RT, or pit gauge as required
E	Ineffective	Ineffective inspection technique/plan was utilized

LoIE Example for CUI

Inspection Category	Inspection Effectiveness Category	Insulation Removed	Insulation Not Removed
A	Highly Effective	For the total surface area: 100 % external visual inspection prior to removal of insulation AND Remove 100 % of the insulation for damaged or suspected areas AND 100 % visual inspection of the exposed surface area with UT, RT, or pit gauge follow-up of the selected corroded areas	For the total surface area: 100 % external visual inspection AND 100 % profile or real-time radiography of damaged or suspect area AND Follow-up of corroded areas with 100 % visual inspection of the exposed surface with UT, RT, or pit gauge
B	Usually Effective	For the total surface area: 100 % external visual inspection prior to removal of insulation AND Remove >50 % of suspect areas AND Follow-up of corroded areas with 100 % visual inspection of the exposed surface area with UT, RT, or pit gauge	For the total surface area: 100 % external visual inspection AND Follow-up with profile or real-time radiography of >65 % of suspect areas AND Follow-up of corroded areas with 100 % visual inspection of the exposed surface with UT, RT, or pit gauge

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LoIE Example for CUI (continue)

Inspection Category	Inspection Effectiveness Category	Insulation Removed	Insulation Not Removed
C	Fairly Effective	For the total surface area: 100 % external visual inspection prior to removal of insulation AND Remove >25 % of suspect areas AND Follow-up of corroded areas with 100 % visual inspection of the exposed surface area with UT, RT, or pit gauge	For the total surface area: 100 % external visual inspection AND Follow-up with profile or real-time radiography of >35 % of suspect areas AND Follow-up of corroded areas with 100 % visual inspection of the exposed surface with UT, RT, or pit gauge
D	Poorly Effective	For the total surface area: 100 % external visual inspection prior to removal of insulation AND Remove >5 % of total surface area of insulation including suspect areas AND Follow-up of corroded areas with 100 % visual inspection of the exposed surface area with UT, RT, or pit gauge	For the total surface area: 100 % external visual inspection AND Follow-up with profile or real-time radiography of >5 % of total surface area of insulation including suspect areas AND Follow-up of corroded areas with 100 % visual inspection of the exposed surface with UT, RT, or pit gauge
E	Ineffective	Ineffective inspection technique/plan was utilized	Ineffective inspection technique/plan was utilized

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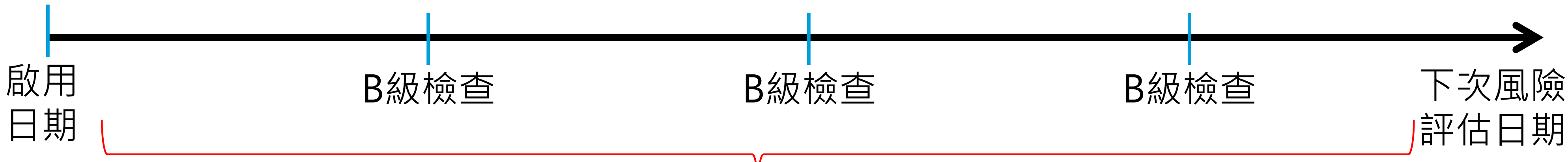
LoIE Example for CUI CISCC

Inspection Category	Inspection Effectiveness Category	Insulation Removed	Insulation Not Removed
A	Highly Effective	For the suspected area: 100 % external visual inspection prior to removal of insulation AND >100 % dye penetrant or eddy current test with UT follow-up of relevant Indications	No inspection techniques are yet available to meet the requirements for an "A" level inspection
B	Usually Effective	For the suspected area: 100 % external visual inspection prior to removal of insulation AND >60 % dye penetrant or eddy current testing with UT follow-up of all relevant indications	No inspection techniques are yet available to meet the requirements for a "B" level inspection
C	Fairly Effective	For the suspected area: 100 % external visual inspection prior to removal of insulation AND >30 % dye penetrant or eddy current testing with UT follow-up of all relevant indications	No inspection techniques are yet available to meet the requirements for a "C" level inspection
D	Poorly Effective	For the suspected area: 100 % external visual inspection prior to removal of insulation AND >5 % dye penetrant or eddy current testing with UT follow-up of all relevant indications	No inspection techniques are yet available to meet the requirements for a "D" level inspection
E	Ineffective	Ineffective inspection technique/plan was utilized	Ineffective inspection technique/plan was utilized

SCC DFs vs. Inspection Effectiveness



E

D_f=500 (等級4)

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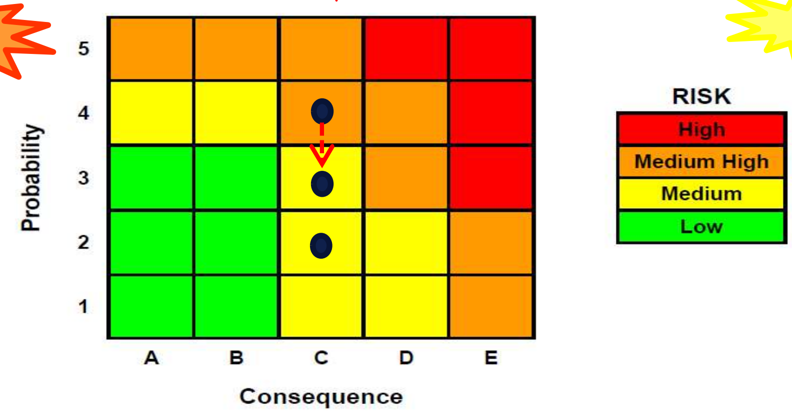
失效可能性等級	損壞因子 (Damage Factor)
1	Df ≦ 1
2	1 ＜ Df ≦ 10
3	10 ＜ Df ≦ 100
4	100 ＜ Df ≦ 1,000
5	Df > 1,000



中

B

D_f=8 (等級2)

S_{VI}	Inspection Effectiveness												
	E	1 Inspection				2 Inspections				3 Inspections			
		D	C	B	A	D	C	B	A	D	C	B	A
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	10	8	3	1	1	6	2	1	1	4	1	1	1
50	50	40	17	5	3	30	10	2	1	20	5	1	1
100	100	80	33	10	5	60	20	4	1	40	10	2	1
500	500	400	170	50	25	300	100	20	5	200	50	8	1
1000	1000	800	330	100	50	600	200	40	10	400	100	16	2
5000	5000	4000	1670	500	250	3000	1000	250	50	2000	500	80	10

S_{VI}	Inspection Effectiveness												
	E	4 Inspections				5 Inspections				6 Inspections			
		D	C	B	A	D	C	B	A	D	C	B	A
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	10	2	1	1	1	1	1	1	1	1	1	1	1
50	50	10	2	1	1	5	1	1	1	1	1	1	1
100	100	20	5	1	1	10	2	1	1	5	1	1	1
500	500	100	25	2	1	50	10	1	1	25	5	1	1
1000	1000	200	50	5	1	100	25	2	1	50	10	1	1
5000	5000	1000	250	25	2	500	125	5	1	250	50	2	1

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Risk mitigation activities

- Reduce the probability of failure
- Equipment Replacement and Repair
- Equipment Modification, Redesign, and Rerating
- Fitness-for-Service Assessment
- Reduce the magnitude of consequence
- Mitigate the primary source of consequence
- Emergency Depressurizing
- Modify Process
- Reduce Inventory
- Emergency Isolation
- Blast-Resistant Construction

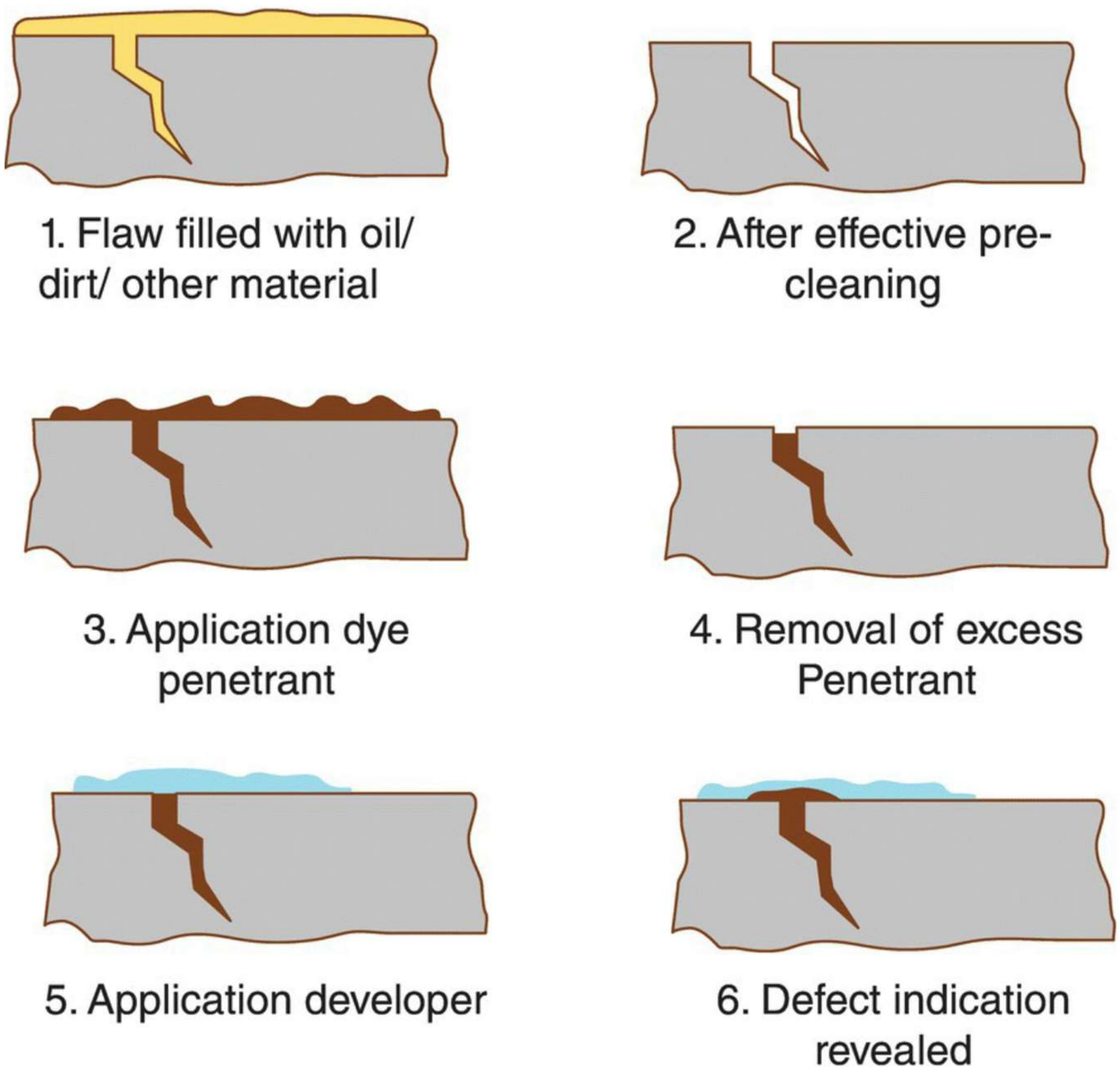
非破壞檢測(NDT)方法

- 液滲檢測 (Liquid penetrant Testing, PT)
- 磁粒檢測 (Magnatic particle Testing, MT)
- 超音波檢測 (Ultrasonic Testing, UT)
- 目視檢測 (Visual Inspection, VT)
- 射線檢測 (Radiographic Testing, RT)
- 渦電流檢測 (Eddy Current Testing, ET)
- 紅外線檢測 (Infrared Thermographer, IR)

Liquid Penetrant Testing

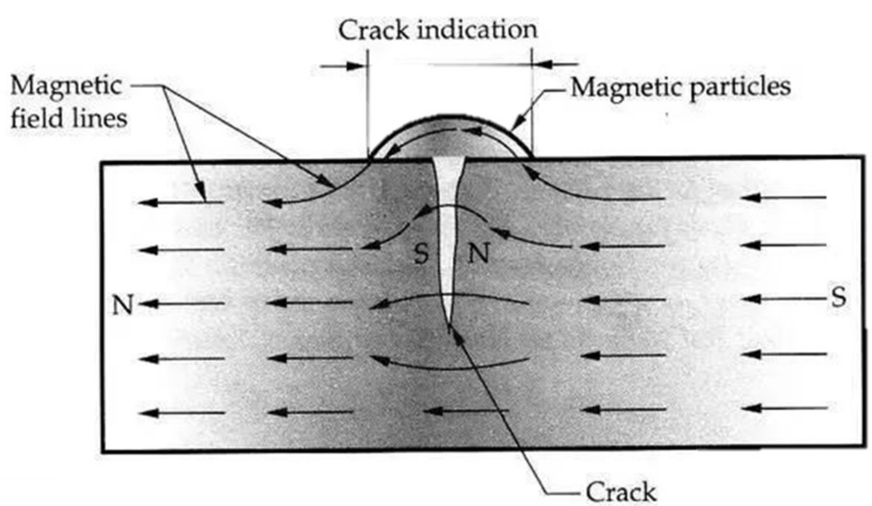
- 目的：利用液體的毛細管作用，將滲透液滲入固體材料表面開口缺陷處，可檢測出非多孔性(Non-porous)、固相材料開口於表面之間斷
- 應用對象：航空太空工業、車輛工業、陶瓷業、工具及工具機業、塑膠業、工地局部檢驗
- 優勢：對小的表面不連續性具有高靈敏度、適用於各種材料、可以快速，低成本地檢查大表面積和大體積零件、直接在零件表面產生指示、壓力罐使滲透性材料非常輕便、所需的材料和設備相對便宜。
- 限制：只能檢測到表面破裂缺陷，表面相對無孔的材料、清潔度要求極高，麻煩且費時、表面清潔度和粗糙度會影響檢測靈敏度、必須以等待間隔執行多個過程操作、適用溫度。

PT方法示意圖

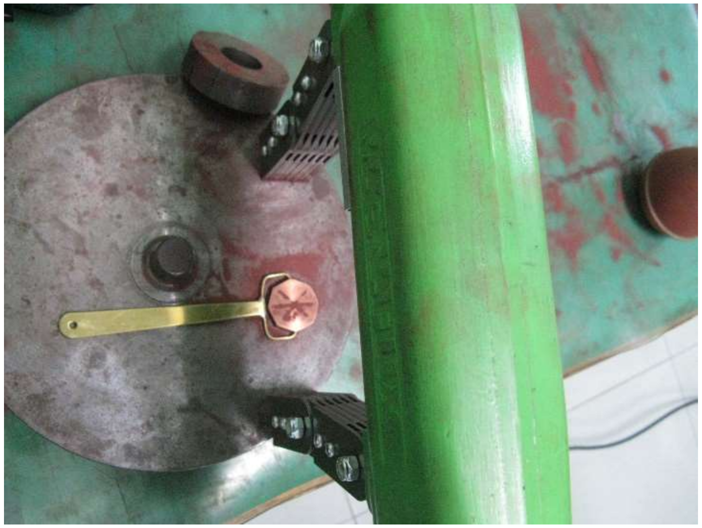

1. Flaw filled with oil/ dirt/ other material
2. After effective pre-cleaning
3. Application dye penetrant
4. Removal of excess Penetrant
5. Application developer
6. Defect indication revealed

Magnatic particle Testing

- 目的：磁化鐵磁性受檢物，使磁力線流向其內部，若遇缺陷、間斷或斷面積改變，此時撒佈磁粒於受檢面，磁粒會在磁漏部位聚集而形成缺陷顯示，可呈現缺陷圖樣。
- 應用對象：鐵磁性材料銲道檢測
- 原理：磁化鐵磁性受檢物，若遇缺陷、間斷或斷面積改變，則磁力線無法穿越而中斷，或在磁路上受阻，在間斷部位產生具有磁極以及磁力線外漏之磁場，此現象稱為磁漏現象，



MT檢測實例



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Ultrasonic Testing
超音波檢測

- 目的：利用「低能量高頻率振動的音波導入材料內部，藉以檢測材料表面或內部缺陷」之非破壞檢測方法。
- 應用對象：壓力容器、儲槽及管線等銲道檢測、板材
- 原理：一般超音波檢則所使用頻率範圍由1MHz至25MHz，由電子訊號產生器，藉由換能器(探頭)發射超音波，再經由接觸媒質傳入試件中，當傳至介面時，超音波可能反射或透射，藉由偵檢、分析反射或透過訊號，則可檢出瑕疵，並可定出檢測位置。
- 此檢測法除用於檢測缺陷外，尚可用於量測試件厚度，進一步若利用音波在材料內部的穿透性差異或音速改變情形，可轉助用於分析材料物理性質、晶粒尺寸或顯微組織等

DNV

UT檢測實例

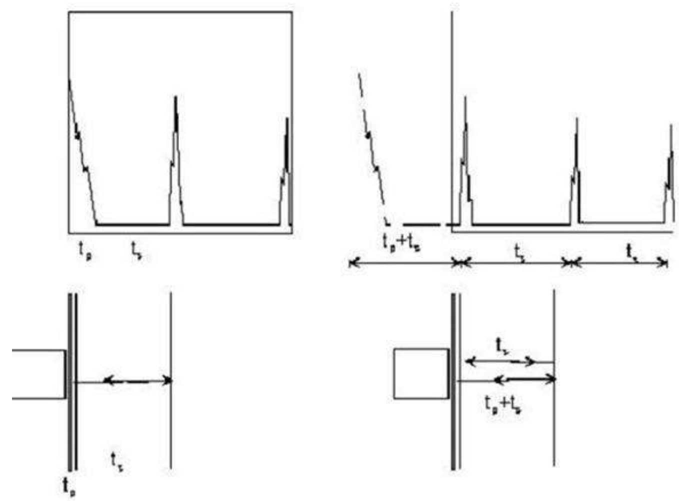

圖 2-2 超音波測厚原理應用圖示

Visual Inspection
目視檢測

- 目的：目視檢測主要是利用眼睛的視覺能力，再加上輔助工具、儀器等來進行直接或間接的偵查及檢視各種物件表面的缺陷。
- 基本原理： 簡單幾何光學原理，藉助平鏡面或凸凹鏡片將所欲檢測物件的影像成比例的放大或縮小以檢測其幾何形狀差異。 物理特性，利用尺、規塊、游標卡尺、點蝕儀等量具測量物件或缺陷大小與深度。
- 應用對象：物件表面的腐蝕、刮痕、瑕疵；銲接後的銲道品質

(a) (b) (c) (d)

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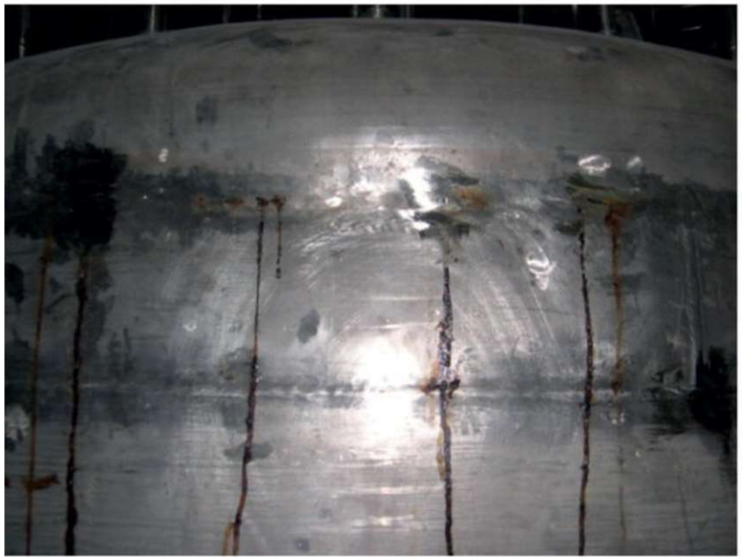
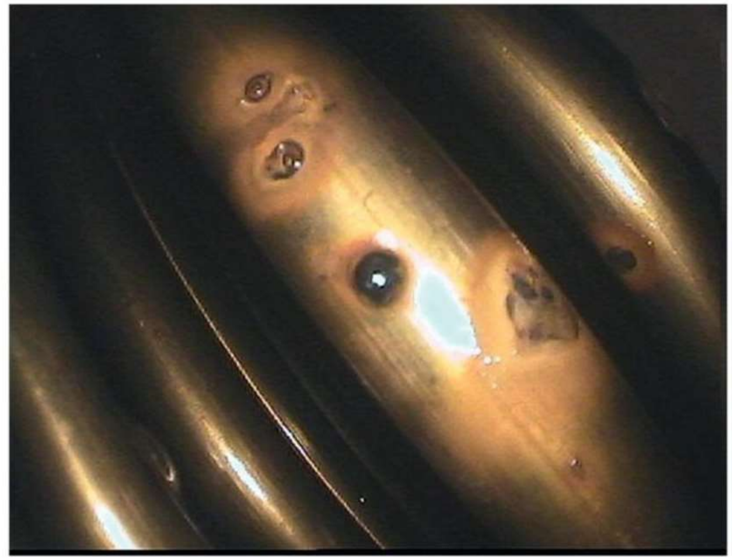
VT檢測實例

(a)

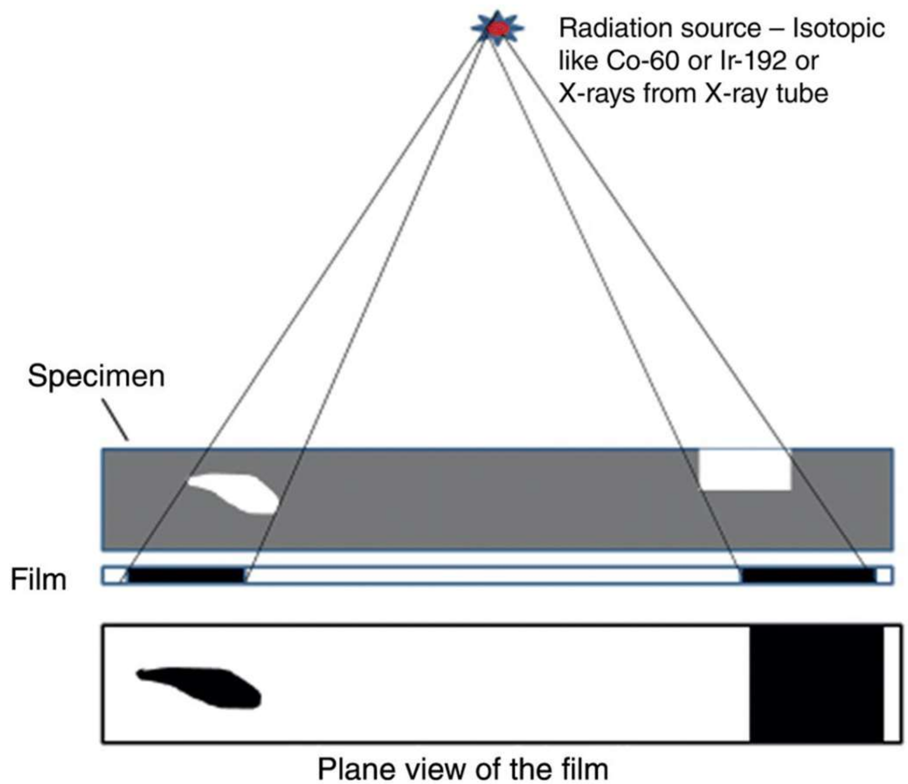


(b)



Radiographic Testing
射線檢測

- 目的：利用電磁輻射（X射線和r射線）的能量，穿透物體過程中會與物質發生相互作用，因吸收和散射使其強度減弱。如果被透照物體局部存在缺陷，該局部區域的透過射線強度就會與周圍產生差異，經由把膠片使其在透過射線的作用下感光，底片上相應部位等會出現黑度差異。
- 應用對象：板材、管材的銲道內部缺陷



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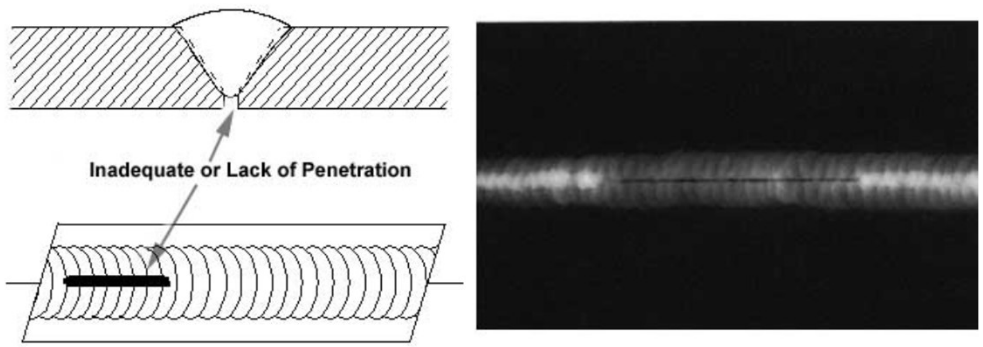
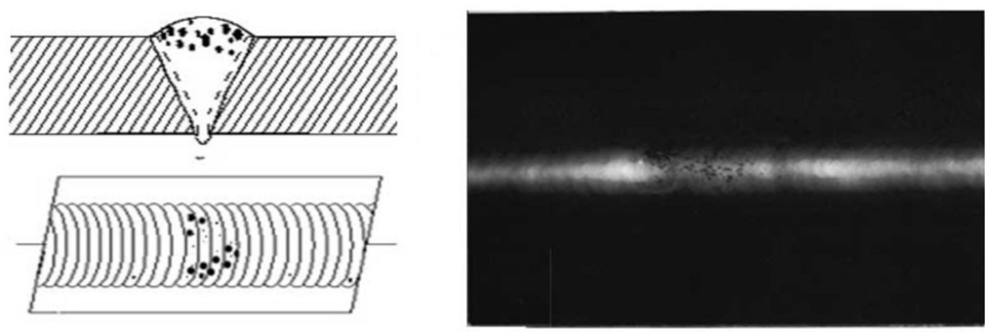
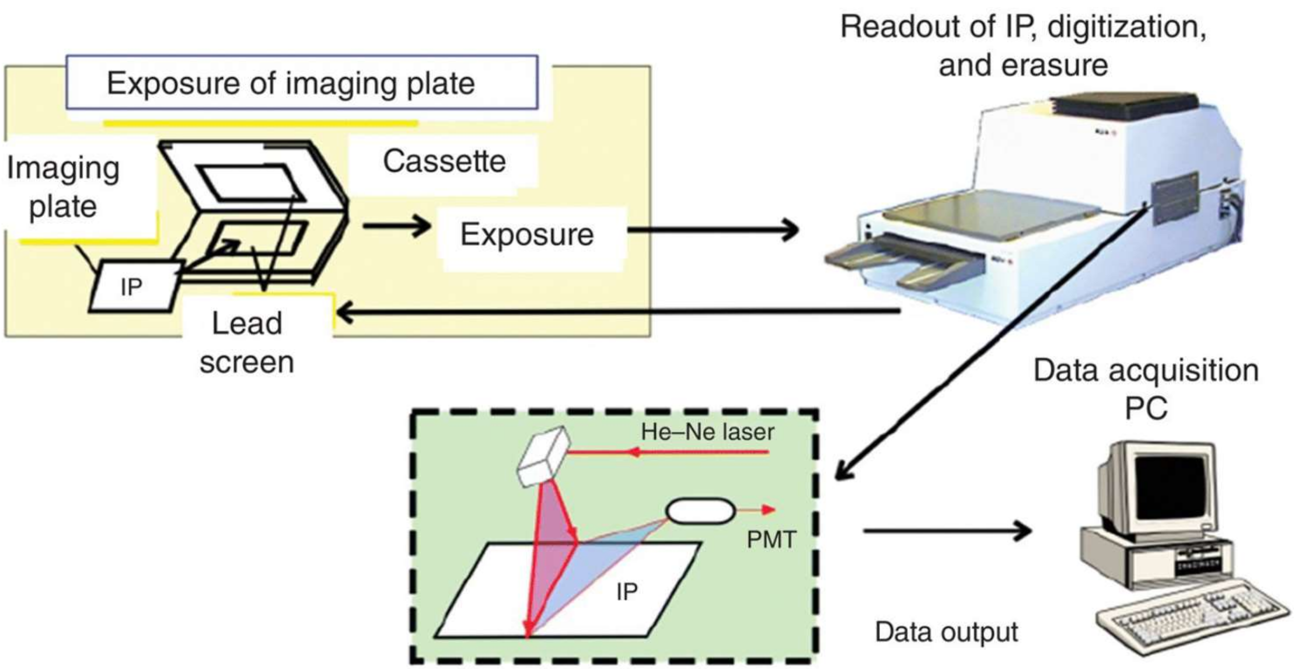
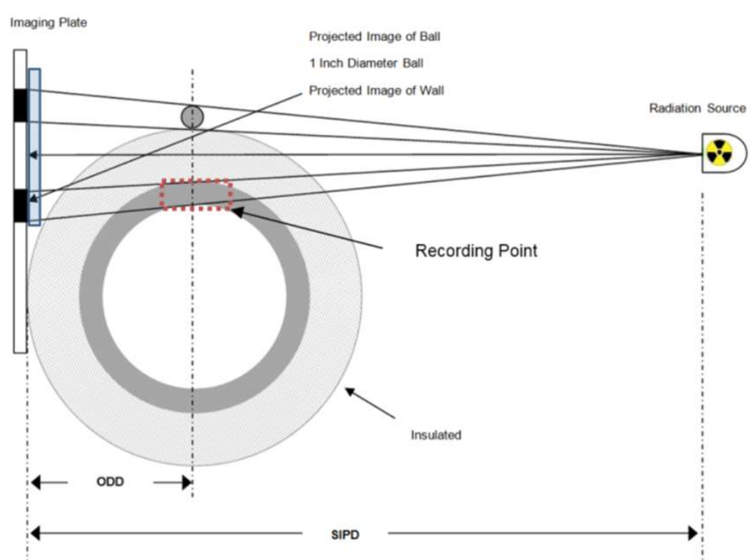
RT檢測實例

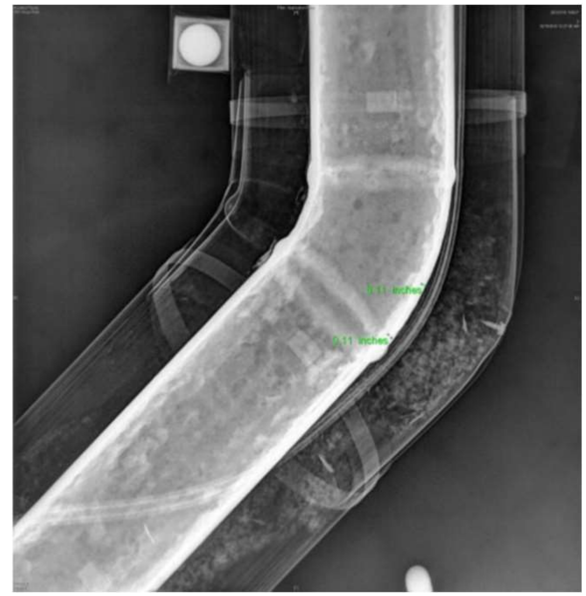




數位式射線檢測

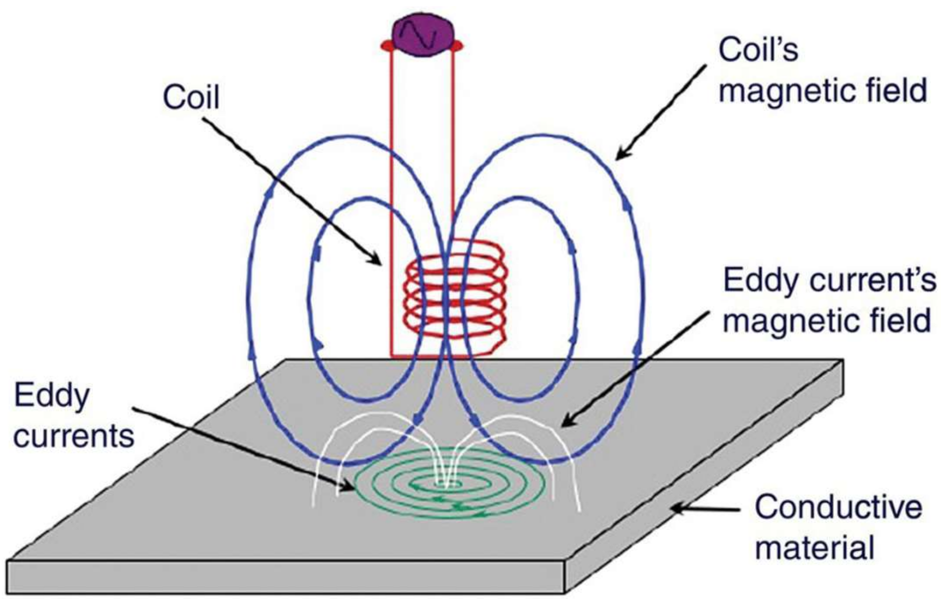

Exposure of imaging plate
Imaging plate
Cassette
Exposure
IP
Lead screen
Readout of IP, digitization, and erasure
Data acquisition PC
He–Ne laser
PMT
IP
Data output


Imaging Plate
Projected Image of Ball
1 Inch Diameter Ball
Projected Image of Wall
Radiation Source
Recording Point
Insulated
ODD
SIPD



Eddy Current Testing
渦電流檢測

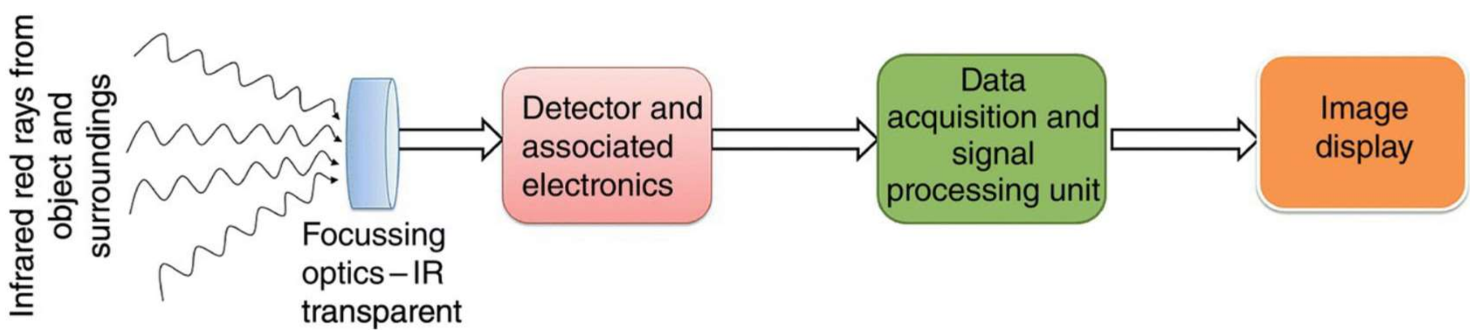
- 目的：渦電流探傷是利用電磁感應原理，在工件檢測表面或近表面層感應產生渦流的無損探傷技術。
- 應用對象：核能電廠的蒸氣產生管路或是發電廠和石油工業的熱交換管線。這個技術非常善於發現坑洞。 管壁的損失或腐蝕可以被檢測，但是不宜測量缺陷的大小。
- 適用於導電材料，包括鐵磁性和非鐵磁性金屬材料等構件的缺陷檢測。



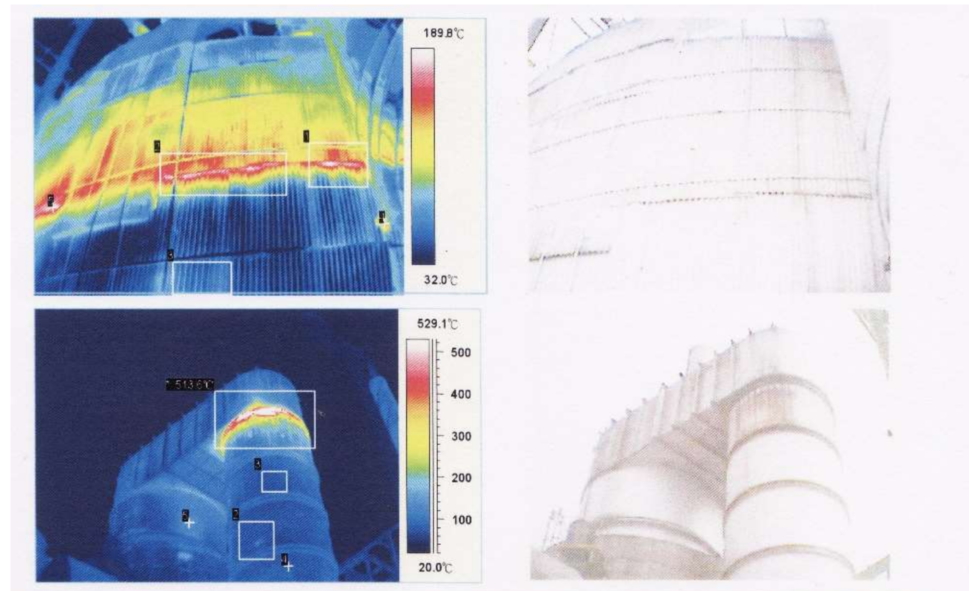
DNV

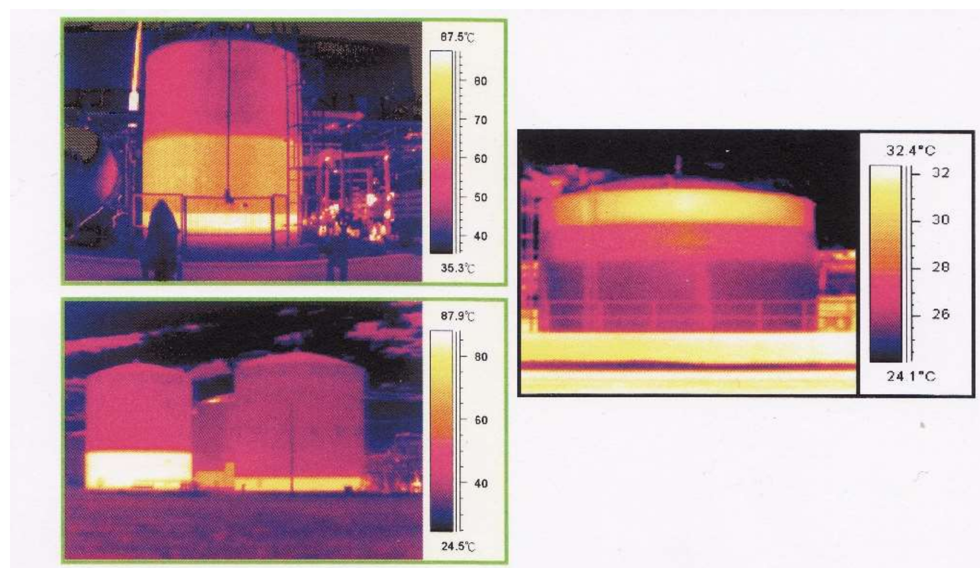
Infrared Thermographer
紅外線檢測

- 目的：透過儀器如熱像儀或紅外線熱影像等，對物體本身散發出的紅外線進行感光成像，進行非接觸的溫度記錄法
- 應用對象：在軍事上，利用紅外線熱影像可以在夜間發現散發熱量的坦克發動機、士兵。在工業上，可以利用熱像儀快速探測出加工件的溫度，從而掌握必要的資訊。由於電動機、電晶體等電子元件發生故障時，往往伴隨著溫度的異常升高，利用紅外線熱影像也可以快速診斷故障。
- 基本運用：
  - 電氣類(連接點緊固問題)
  - 機械類(軸承、聯軸器、齒輪/齒輪箱)
  - 保溫/隔熱類(耐火磚或隔熱層或保溫層磨損崩落檢查(熱損)、爐壁鍋爐、反應爐、裂解爐、高爐、加熱爐、保溫管線、儲槽、冷凍/加熱系統、爐管檢查、儲槽液位檢查)



紅外線檢測實例


189.8℃
32.0℃
529.1℃
500
400
300
200
100
20.0℃


87.5℃
80
70
60
50
40
35.3℃
87.9℃
80
60
40
24.5℃
32.4°C
32
30
28
26
24 1°C

Capabilities of NDT

	Damage/Defect			Common Examination Methods Used to Identify [Note (1)]																	
				Surface					Subsurface					Other Methods					
Mechanism	Mode [Note (2)]	Damage Mechanism	Manufacturing Defect	Visual (Including Borescope)—VT [Note (3)]	Liquid Penetrant—PT [Note (3)]	Fluorescent Liquid Penetrant—FPT [Note (3)]	Magnetic Particle—MT [Note (4)]	Wet Fluorescent Magnetic Particle—WFMT [Note (4)]	Ultrasonics for Thickness—UTT	Ultrasonics—Straight Beam—UTS	Ultrasonics—Shear Wave—UTSW	Ultrasonics—Shear Wave Adv. Techniques—UTSWA	Radiography—RT	Eddy-Current—ET	Acoustic Emission—AE	Dimensional Measurements	Hardness Tests	In-Place Metallography (Replication)	Boat/Plug Sample
885°F embrittlement	Metallurgical damage	X																	X
Abrasive wear	Metal loss	X		X					X							X			
Acid dew point corrosion	Metal loss	X		X					X	X									X
Adhesive wear	Metal loss	X		X	X				X							X			
Amine corrosion	Metal loss	X		X					X										
Amine cracking	Cracking	X		X			X	X			X	X			X				
Ammonia grooving	Metal loss	X		X					X										
Ammonia stress corrosion cracking	Cracking	X		X			X	X			X	X		X					
Carbonate stress corrosion cracking	Cracking	X		X				X			X	X							
Carburization	Metallurgical damage	X															X		X
Casting porosity/voids	Casting defects		X	X	X	X				X	X	X	X						X
Catastrophic carburization (metal dusting)	Metal loss	X		X					X	X	X	X							X
Caustic cracking (caustic embrittlement)	Cracking	X		X		X		X			X	X	X	X					
Caustic corrosion (caustic gouging)	Metal loss	X		X						X			X	X					X
Cavitation	Metal loss	X		X															
Chelant corrosion	Metal loss	X		X					X					X					X
CO_2 corrosion	Metal loss	X																	
Cold cracking	Weld defects		X	X	X	X	X	X		X	X	X	X						X
Corrosion—fatigue	Cracking	X		X	X	X	X	X		X	X	X		X	X				X
Corrosion under insulation (CUI)	Metal loss	X		X					X	X									
Creep	Cracking	X								X	X	X			X	X		X	X
Crevice corrosion	Metal loss	X		X															X
Decarburization	Metallurgical damage	X															X		X

	Damage/Defect			Common Examination Methods Used to Identify [Note (1)]																	
				Surface					Subsurface					Other Methods					
Mechanism	Mode [Note (2)]	Damage Mechanism	Manufacturing Defect	Visual (Including Borescope)—VT [Note (3)]	Liquid Penetrant—PT [Note (3)]	Fluorescent Liquid Penetrant—FPT [Note (3)]	Magnetic Particle—MT [Note (4)]	Wet Fluorescent Magnetic Particle—WFMT [Note (4)]	Ultrasonics for Thickness—UTT	Ultrasonics—Straight Beam—UTS	Ultrasonics—Shear Wave—UTSW	Ultrasonics—Shear Wave Adv. Techniques—UTSWA	Radiography—RT	Eddy-Current—ET	Acoustic Emission—AE	Dimensional Measurements	Hardness Tests	In-Place Metallography (Replication)	Boat/Plug Sample
Dissimilar metal weld cracking (DMW)	Cracking	X		X	X	X	X	X			X	X							
Dissolved O_2 attack	Metal loss	X		X										X					X
Electrical discharge	Metal loss	X		X															
Erosion	Metal loss	X		X					X	X	X	X				X			
Erosion—droplets	Metal loss	X		X					X	X	X	X				X			
Erosion—solids	Metal loss	X		X					X	X	X	X				X			
Erosion/corrosion	Metal loss	X		X					X	X	X	X				X			
Fatigue	Cracking	X		X	X	X	X	X		X	X	X		X	X				X
Fatigue, contact	Cracking	X		X	X	X		X							X				
Fatigue, thermal	Cracking	X		X	X	X	X	X		X	X	X		X	X				X
Fatigue, vibration	Cracking	X		X	X	X	X	X		X	X	X		X	X				X
Filiform, corrosion	Metal loss	X		X															X
Flow-accelerated corrosion (FAC)	Metal loss	X		X					X					X					
Flue gas dew point corrosion	Metal loss	X		X					X										
Fretting	Metal loss	X		X	X	X													X
Fuel ash corrosion	Metal loss	X																	
Galvanic corrosion	Metal loss	X		X															X
Graphitization	Metallurgical damage	X															X	X	X
High temp H_2/H_2S corrosion	Metal loss	X		X					X				X						
Hot cracking	Weld defects		X	X	X	X	X	X					X		X				X
Hot tensile	Metallurgical damage	X		X												X		X	X
Hydrochloric acid corrosion	Metal loss	X		X					X										
Hydrofluoric acid corrosion	Metal loss	X		X					X				X						

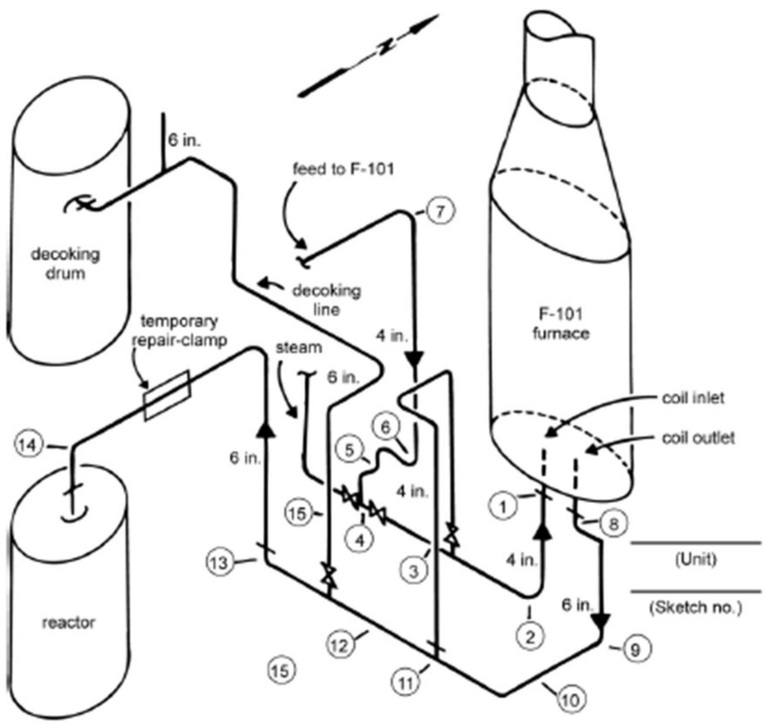
Capabilities of NDT

	Damage/Defect			Common Examination Methods Used to Identify [Note (1)]															
				Surface					Subsurface					Other Methods					
Mechanism	Mode [Note (2)]	Damage Mechanism	Manufacturing Defect	Visual (Including Borescope)—VT [Note (3)]	Liquid Penetrant—PT [Note (3)]	Fluorescent Liquid Penetrant—FPT [Note (3)]	Magnetic Particle—MT [Note (4)]	Wet Fluorescent Magnetic Particle—WFMT [Note (4)]	Ultrasonics for Thickness—UTT	Ultrasonics—Straight Beam—UTS	Ultrasonics—Shear Wave—UTSW	Ultrasonics—Shear Wave Adv. Techniques—UTSWA	Radiography—RT	Eddy-Current—ET	Acoustic Emission—AE	Dimensional Measurements	Hardness Tests	In-Place Metallography (Replication)	Boat/Plug Sample
Hydrogen damage (HTHA)	Cracking	X								X	X	X			X				X
Hydrogen embrittlement	Metallurgical damage	X	X																X
Hydrogen-induced crack (HIC)	Cracking	X				X		X		X	X	X		X	X			X	X
Intergranular corrosion	Metal loss	X																X	X
Knife-line attack	Cracking		X	X						X	X	X			X				
Lack-of-fusion	Weld defects		X							X	X	X	X						X
Lack-of-penetration	Weld defects		X	X	X		X			X	X	X	X						X
Liquid metal embrittlement	Cracking	X	X		X	X	X	X		X	X	X			X			X	X
Liquid (molten) slag attack	Metal loss	X		X					X	X									X
Microbiological induced corrosion (MIC)	Metal loss	X		X					X	X									X
Napthenic acid corrosion	Metal loss	X		X					X				X						
Oxidation corrosion	Metal loss	X		X					X	X									X
Phenol (carbolic acid)	Metal loss	X		X					X				X						
Phosphate attack	Metal loss	X							X										X
Phosphoric acid corrosion	Metal loss	X		X					X				X						
Pitting corrosion	Metal loss	X		X	X					X				X					X
Polythionic acid cracking	Cracking	X			X	X				X	X	X							
Porosity	Weld defects		X							X	X	X	X						X
Selective leaching (dealloying)	Metal loss	X																X	X
Sensitization	Metallurgical damage	X																X	X
Sigma and chi phase	Metallurgical damage	X																X	X
Sigma phase	Metallurgical damage	X																X	X

	Damage/Defect			Common Examination Methods Used to Identify [Note (1)]															
				Surface					Subsurface					Other Methods					
Mechanism	Mode [Note (2)]	Damage Mechanism	Manufacturing Defect	Visual (Including Borescope)—VT [Note (3)]	Liquid Penetrant—PT [Note (3)]	Fluorescent Liquid Penetrant—FPT [Note (3)]	Magnetic Particle—MT [Note (4)]	Wet Fluorescent Magnetic Particle—WFMT [Note (4)]	Ultrasonics for Thickness—UTT	Ultrasonics—Straight Beam—UTS	Ultrasonics—Shear Wave—UTSW	Ultrasonics—Shear Wave Adv. Techniques—UTSWA	Radiography—RT	Eddy-Current—ET	Acoustic Emission—AE	Dimensional Measurements	Hardness Tests	In-Place Metallography (Replication)	Boat/Plug Sample
Sliding wear	Metal loss	X		X					X							X			
Softening (over aging)	Metallurgical damage	X															X		X
Sour water corrosion (acidic)	Metal loss	X		X					X				X						
Spheroidization	Metallurgical damage	X															X	X	X
Strain aging	Metallurgical damage	X															X		X
Stray current corrosion	Metal loss	X		X					X	X	X	X							
Sulfidation	Metal loss	X																X	X
Sulfide-stress cracking (SSC)	Cracking	X			X	X	X	X		X	X	X		X	X			X	X
Sulfuric acid corrosion	Metal loss	X		X					X				X						
Temper embrittlement	Metallurgical damage	X	X																X
Under deposit corrosion	Metal loss	X							X	X									X
Uniform corrosion	Metal loss	X		X					X	X	X	X				X			
Weld decay	Metal loss	X		X						X	X	X							X
Weld metal crater cracking	Weld defects		X	X	X	X	X	X		X	X	X			X				X
Weld metal fusion line cracking	Weld defects		X	X	X	X	X	X		X	X	X	X		X				X
Weld metal longitudinal cracking	Weld defects		X	X	X	X	X	X		X	X	X	X		X				X
Weld metal root cracking	Weld defects		X							X	X	X	X		X				X
Weld metal toe cracking	Weld defects		X	X	X	X	X	X		X	X	X	X		X				X
Weld metal transverse cracking	Weld defects		X	X	X	X	X	X		X	X	X	X		X				X
Weld metal underbead cracking	Weld defects		X							X	X	X	X		X				X

Condition monitoring locations, CMLs

- 管線統上進行定期檢查以評估管線的指定區域。
  Designated areas on piping systems where periodic examinations are conducted in order to assess the condition of the piping.
- CML可以包含一個或多個檢查點，並利用基於預測損壞機制的多種檢查技術。
  One or more examination points and utilize multiple inspection techniques that are based on the predicted damage mechanism(s).



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API 570 Guidance (5.6.3) CMLs

- **CML數量和位置依據檢測歷史、潛在腐蝕劣化機制和失效的後果**
  A decision on the type, number and location of the CML’s should consider results from previous inspections, the patterns of corrosion and damage that are expected and the potential consequence of loss of containment.

- **學理上，如果能認定存在的是均勻腐蝕，僅規劃一處CML進行觀察是可行的。實際上，均勻腐蝕是很少見的，而且實際上可能相當局部，因此可能需要額外的CML。**
  In theory, a circuit subject to perfectly uniform corrosion could be adequately monitored with a single CML. In reality, corrosion is seldom truly uniform and in fact may be quite localized, so additional CMLs may be required.

- **CML最佳化**
  Inspectors must use their knowledge of the process unit to optimize the CML selection for each circuit, **balancing the effort of collecting the data with the benefits provided by the data.**

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CMLs Allocation

- 配件、分支、死角、注入點 (管線複雜性高的位置)
- 有較高的短期/長期（或最大/平均）腐蝕率
- 更高程度的製程可變性（將影響局部腐蝕的製程參數）
- 具有類似的腐蝕環路，在其他工廠或行業中曾經發生了意外故障
- 頻繁的冷熱交替處
- 帶有穿過絕緣層伸出的部件的低溫設備
- 冷熱設備之間的介面處 (接口處)

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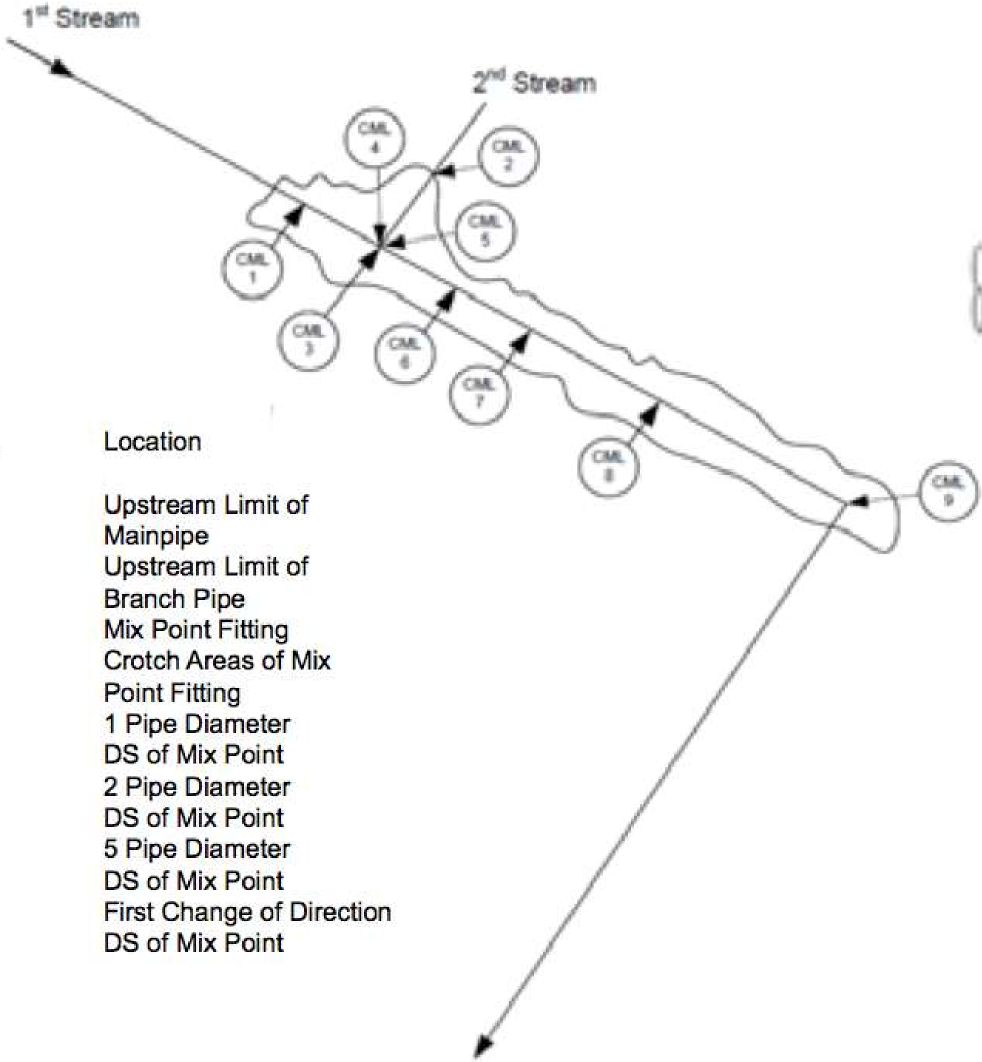
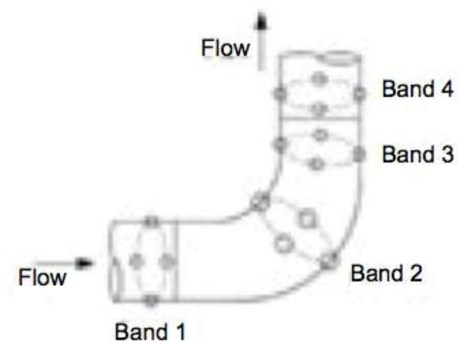
檢測規劃原則-管線注入點

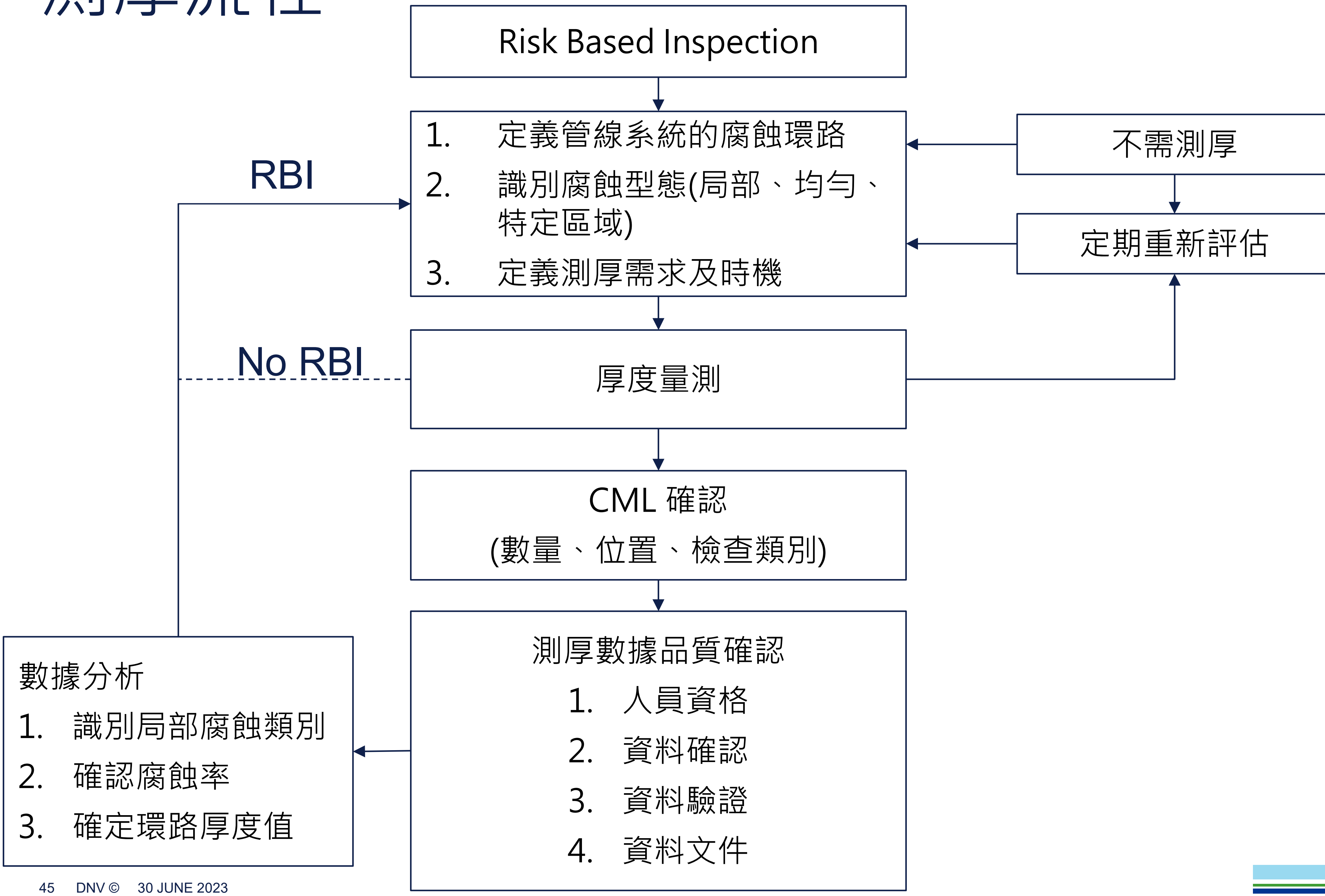


CML	Location
1	Upstream Limit of Mainpipe
2	Upstream Limit of Branch Pipe
3	Mix Point Fitting
4,5	Crotch Areas of Mix Point Fitting
6	1 Pipe Diameter DS of Mix Point
7	2 Pipe Diameter DS of Mix Point
8	5 Pipe Diameter DS of Mix Point
9	First Change of Direction DS of Mix Point



Ref. INSPECTIONEERING JOURNAL-A Discussion on the Piping Thickness Management Process

測厚流程



Ref. INSPECTIONEERING JOURNAL-A Discussion on the Piping Thickness Management Process

總結

- 提高安全性並降低成本
  - 將成本與風險緩解效果進行比較，從而優化長期和短期成本和風險。
  - 促進現在和未來設備劣化風險的持續評估和記錄。
  - 由現在和長期的風險發展，從而能夠制定更有效的維護計劃。
- 過去檢查的有效性應成為確定當前風險的一部分，應該透過未來的檢查活動來管理未來的風險。
- 為更有效的檢查技術可以將未來的風險降低到可接受的水平。
- 沒有單一種檢查技術是可以全面的，透過多種檢查技術的交互應用，可以確認設備系統安全性，更能有效的管理公司的資產。

WHEN TRUST MATTERS

感謝聆聽

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