石化產業老舊工廠風險暨資產完整性管理

主講人：翁榮洲 財團法人工業技術研究院材料與化工研究所

石化產業製程安全管理邁向永續發展論壇

地點：高雄國際會議中心

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50% of European major hazard 'loss of containment' events arising from technical plant failures were primarily due to **ageing plant mechanisms** such as erosion, corrosion and fatigue. This data analysis for HSE (Ageing Plant Study Phase 1 report [2]) has shown that across Europe, between 1980 and 2006, there have been 96 major accident potential loss of containment incidents reported in the EU Major Accident Database (MARS) which are estimated to be primarily caused due to ageing plant mechanisms. This represents 30% of all reported 'major accident' loss of containment events in the MARS database, and 50% of the technical integrity and control and instrumentation related events. These 'ageing' events equate to an overall loss of 11 lives, 183 injuries and over 170Million € of economic loss.

This finding is supported by RIDDOR data which has shown that between 1996 and 2008 it is estimated that there have been 173 loss of containment incidents reported in RIDDOR that can be attributed to ageing plant mechanisms.

Deaths and Injuries Statistics for MARS Reportable Major Accident Hazard Incidents

Class	Total	Deaths			Injuries		
	No. Incidents	Incidents	Total Deaths	Deaths per event	Incidents	Total Injuries	Injuries per Event
All events	348	57	124	2.2	140	4,201[1]	30.0
(excluding')					139	1,959	14.1
All interity	149	11	35	3.2	51	768	15.1
Interity aging[2]	57	3	4	1.3	21	125	6.0
C&I aging[3]	21	2	4	2.0	4	32	8.0
Other aging[4]	23	2	3	1.5	7	47	6.7
All aging[5]	96	7	11	1.6	30	183	6.1

Notes：

1 One incident with 2242 injuries.

2 Aging from corrosion, erosion, stress corrosion cracking, fatigue, corrosion fatigue, vibration and wear.

3 Aging where Control and Instrumentation (C&I) is a factor.

4 Aging from other sources (safeguards, structural, etc.)

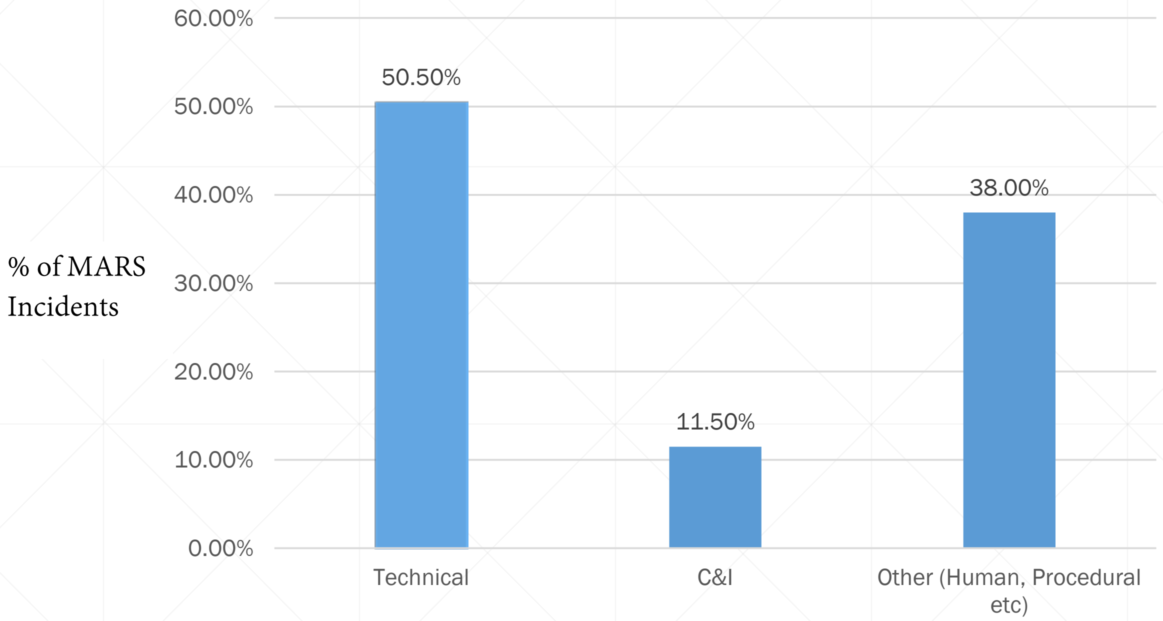
5 All aging sources (this total is five less than the sum of the three above categories as five of those incidents are 'double counts' since classified in two or more aging categories from notes 2,4).

Total Losses (Million € Equivalent) for MARS Reportable Major Accident Hazard Incidents

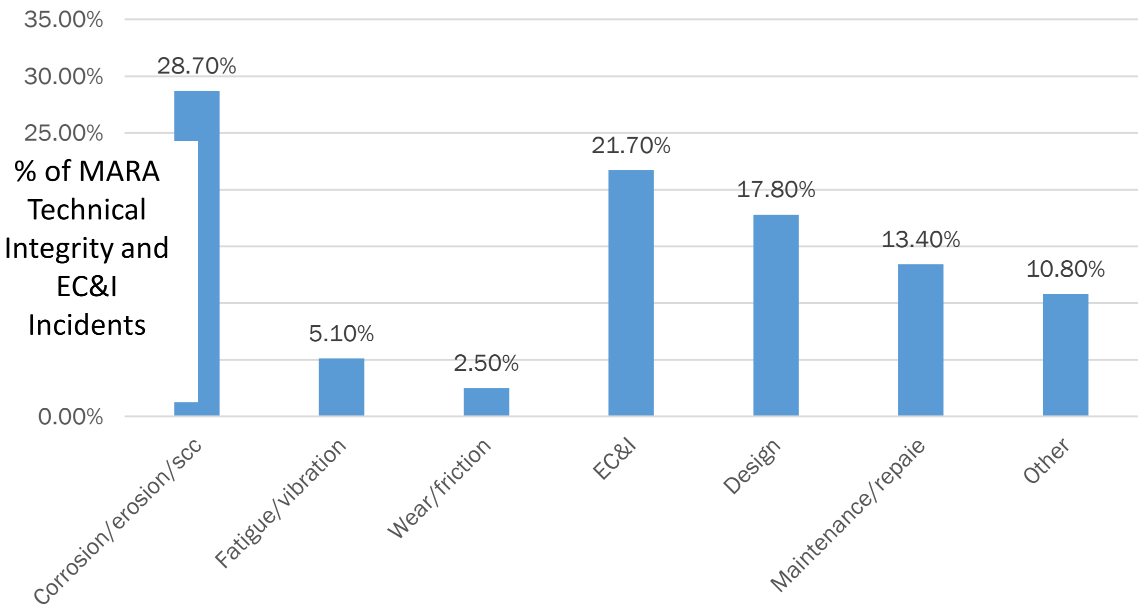
Class	Total Losses(M €)	Incidents Where Loss Occurred (no.)	Average Loss per Event (M €)	All Incidents	Average Loss per Event (M €)
All Events	794.7	107	7.4	348	2.3
All Integrity	329.1	42	7.8	149	2.2
Integrity Aging	149.7	18	8.3	57	2.6
C&I Aging	17.8	7	2.5	21	0.8
Other Aging	3.6	4	0.9	23	0.2
All Aging	171.0	28	6.1	96	1.8

Source：European Union Major Accident Reporting System (MARS) operated by the European Commission Joint Research Centre.

High Level Categorization of MARS Incidents



Causes of Technical Integrity Incidents in MARS Data



老當益壯,未老先衰,不知老之將至?

"AGEING IS NOT ABOUT HOW OLD YOUR EQUIPMENT IS; IT'S ABOUT WHAT YOU KNOW ABOUT ITS CONDITION, AND HOW THAT'S CHANGING OVER TIME"

Ageing is the effect whereby a component suffers some form of material deterioration and damage (usually, but not necessarily, associated with time in service) with an increasing likelihood of failure over the lifetime.

All types of equipment can be susceptible to ageing mechanisms."

Definition from UK Health and Safety Executive, Research Report 509 on Ageing Plant, 2006

工廠壽命?

運轉年限

- 一般工場沒有操作年限，正確評估及維護即可安全操作

設計壽命,物理壽命or功能壽命

關廠--經濟壽命

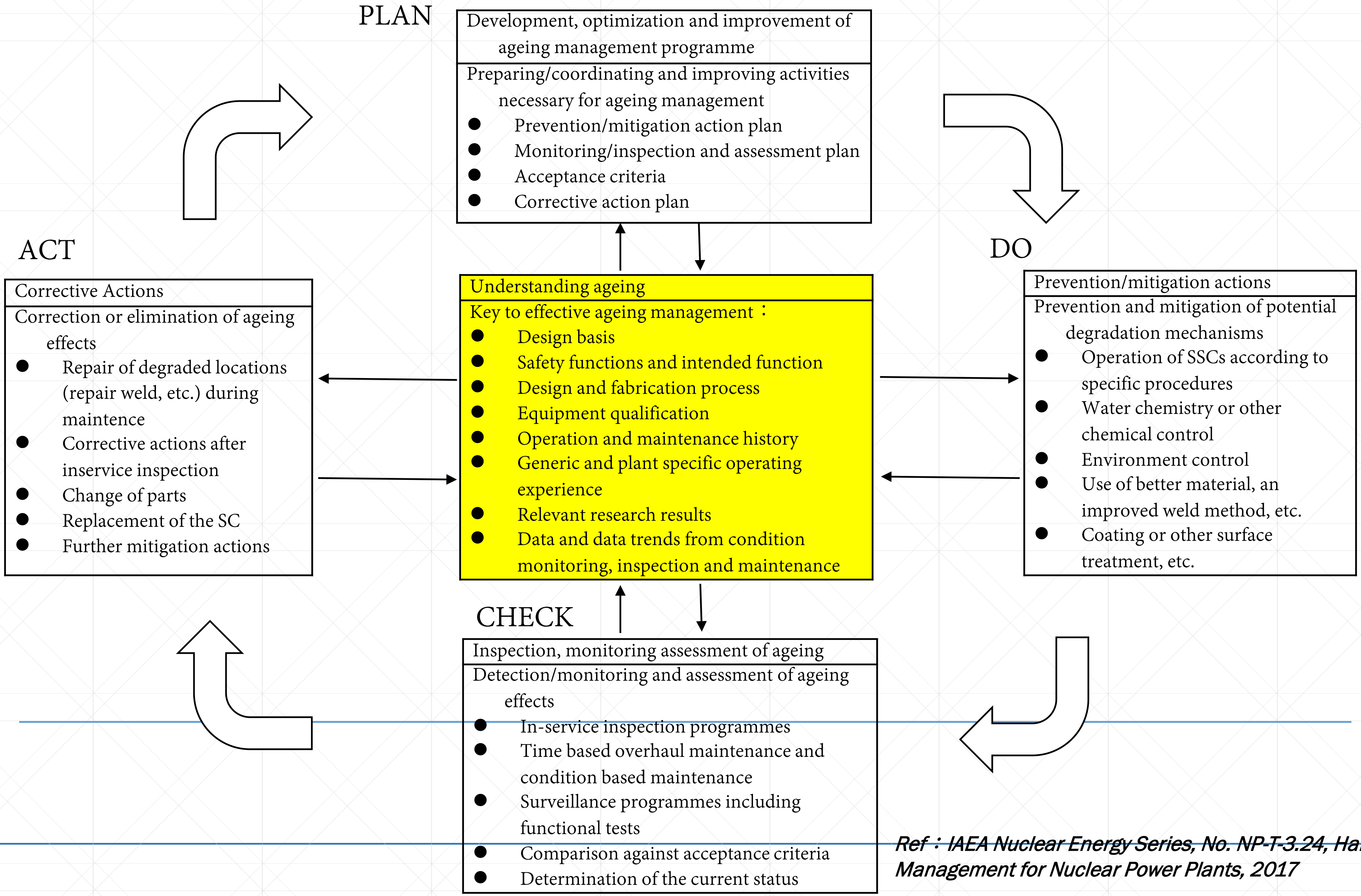
- 核能電廠每十年換照,運轉執照40年

美國核電廠**延役至60年甚至80年**台灣核電廠40年**除役(目前法令規定)**

為何工廠的風險上升?

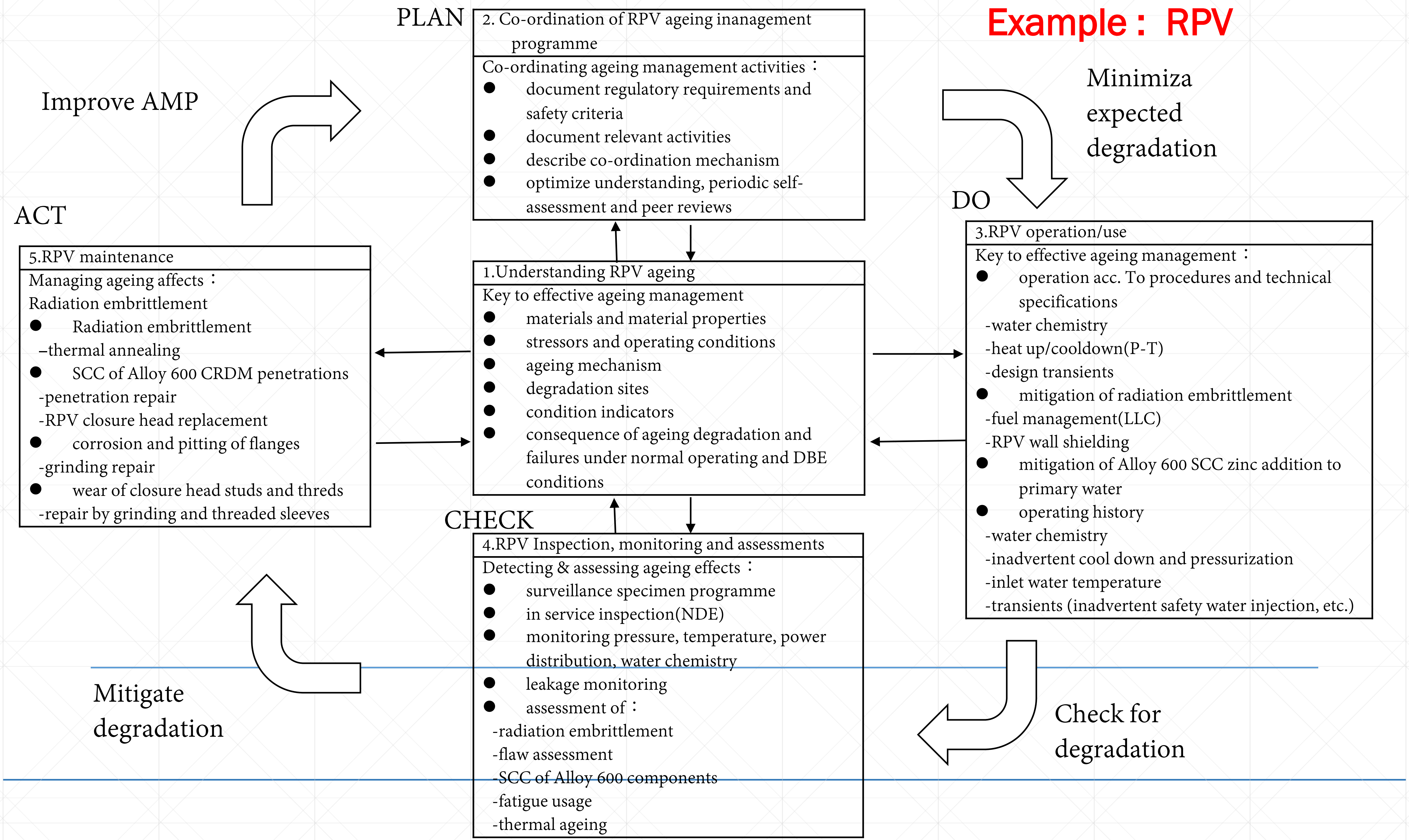
- 設備老化
- 經驗喪失
- 能力缺乏
- 員工期望變更
- **管理管制和管理責任不足**

延壽--核能電廠老化管理



Ref：IAEA Nuclear Energy Series, No. NP-T-3.24, Handbook on Ageing Management for Nuclear Power Plants, 2017

FIG.10. Systematic approach to ageing management. SC-structure and componment；SSC-structure, system and component【2】



FUG.11. Key elements of a pressurized water reactor AMP for a RPV. DBE-design basis event：LLC - low leakage core.

核能電廠執照更新申請法規文件

老化管理&安全評估

- 整體性電廠評估
- 時效限度分析評估 (time-limited aging analyses ，TLAA)
  - ✓證明安全分析仍有效、或重新分析、或說明可以有效監視老化效應
  - ✓例如:疲勞分析、PT curve、管路應力分析、管壁厚度計算、設備環境驗證分析、圍阻體tendon預力分析等
  - ✓由電廠的design base documents中找出TLAA項目

原設計基準修改

- 終期安全分析報告修正
- 運轉規範的修改

環評

- 環境影響報告(10CFR51)

整體性電廠評估

- Scope評估—訂出所須評估的系統/設備
  - ✓ passive, long-lived
  - ✓ 安全相關設備
  - ✓ 會造成安全設備故障的非安全設備
  - ✓ 特定法規要求的設備
    - ✓ Fire protection(50.48)、EQ (50.49) 、Pressurized thermal shock (50.61-PWR) 、ATWS(50.62) 、station black(50.63)
- 老化管理審查(AMR)
  - ✓ 引用EPRI老化管理工具書
  - ✓ 土木結構類 (EPRI-1002950)—混凝土龜裂、多孔性、腐蝕、風化、微生物作用 、強度下降等
  - ✓ 機械類 (EPRI-1003056)—輻射效應、龜裂、腐蝕、疲勞、磨損、脆化、薄化、微生物作用等
  - ✓ 儀電類 (EPRI-1003057)—因熱或輻射線或溼度等因素，引起電纜線包覆材料的脆化、龜裂、融化、氧化等現象
  - ✓ 依專業分別審查評估各系統的老化現象
- 引用維護法規的維護計畫

設備完整性(MI), 資產完整性(AI)

MI can be defined as the management of critical process equipment to ensure it is designed and installed correctly and that it is operated and maintained properly.

定義：管理關鍵製程設備，確保正確的設計和安裝，以及適當的操作和維護

1.適用範圍

2.建立書面程序

3.員工作業程序訓

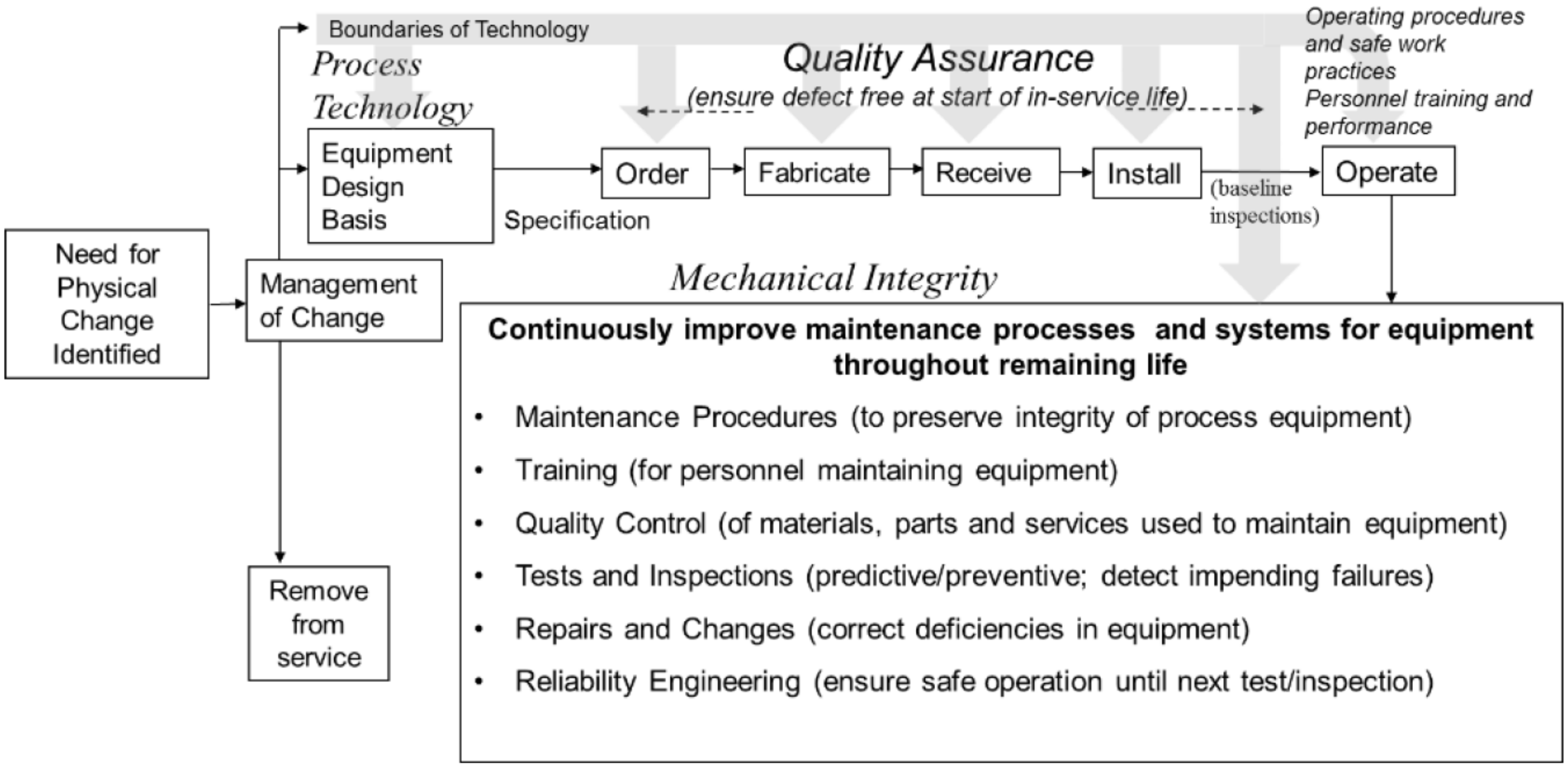
4.檢查及測試

5.缺失未矯正則不

6.品質保證計畫

設備生,老,病,死的管理

Asset Lifecycle Management



- 十年前的工廠設計而現在的工廠設計有何不同?
- 設備完整性管理只要關心關鍵性設備?

Ageing Asset Types

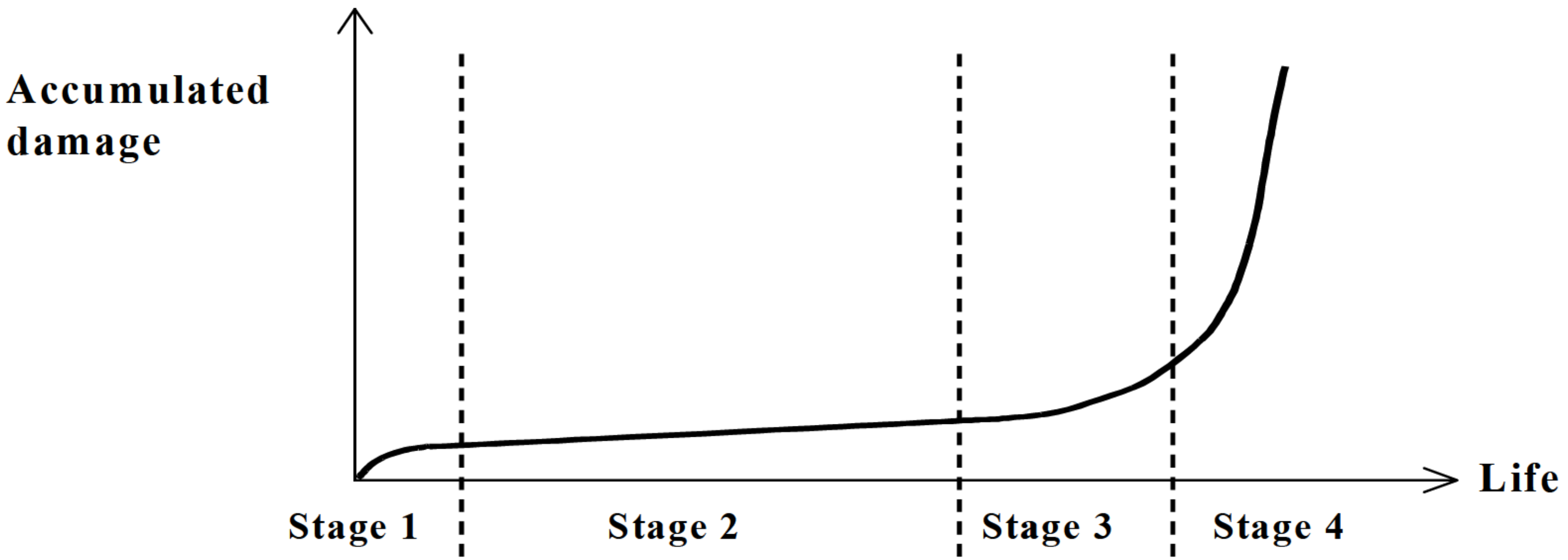
- Primary containment systems
- Control & Mitigation Measures, i.e. Safeguards
- EC&I systems
- Structures

Ageing Mechanisms Affecting Physical Assets

Ageing Mechanism	Primary Containment	Structures	Safeguards	EC&I
Corrosion	✓	✓	✓	✓
Stress Corrosion Cracking	✓	✓	✓	
Erosion	✓	✓	✓	✓
Fatigue	✓	✓	✓	
Embrittlement	✓	✓		✓
Physical damage	✓	✓	✓	✓
Spalling		✓		
Weathering		✓	✓	
Expansion/ contraction due to temperature changes (process or ambient) or freezing	✓	✓	✓	✓
Instrument drift				✓
Dry joint development				✓
Detector poisoning				✓
Subsidence		✓	✓	

老化速率與損傷累積

Variation of accumulated damage during equipment service



Numbers of defects detected in equipment

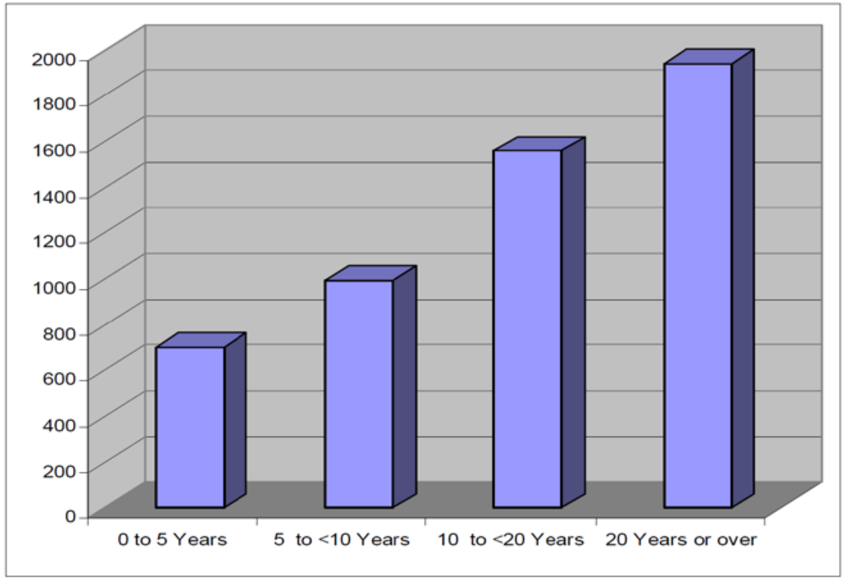


Figure 4a Defects detected by SAFed inspections of pressure vessels in 4 years

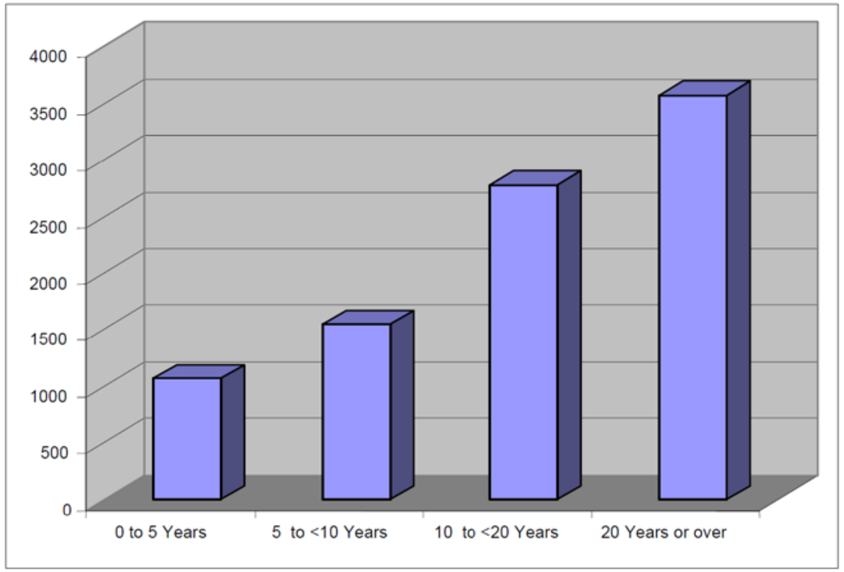
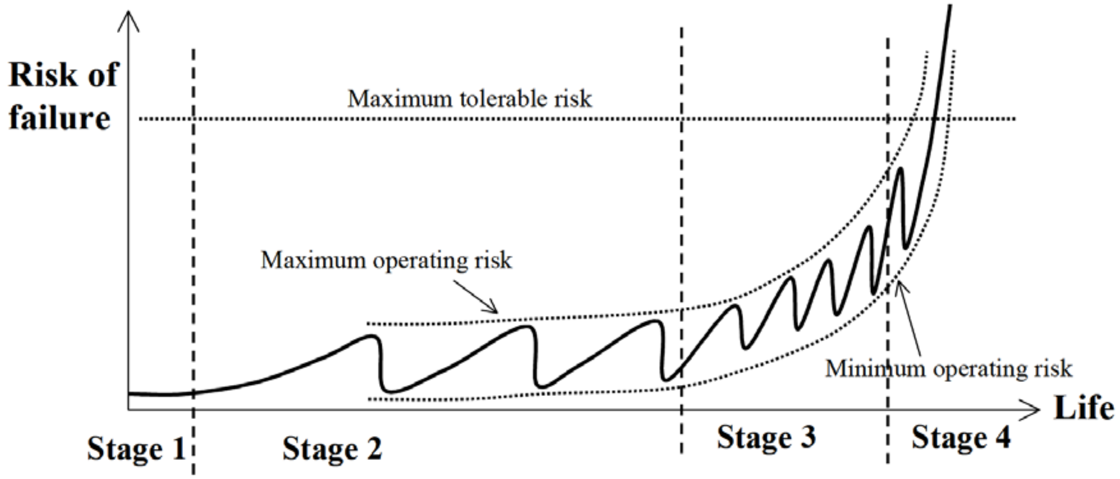


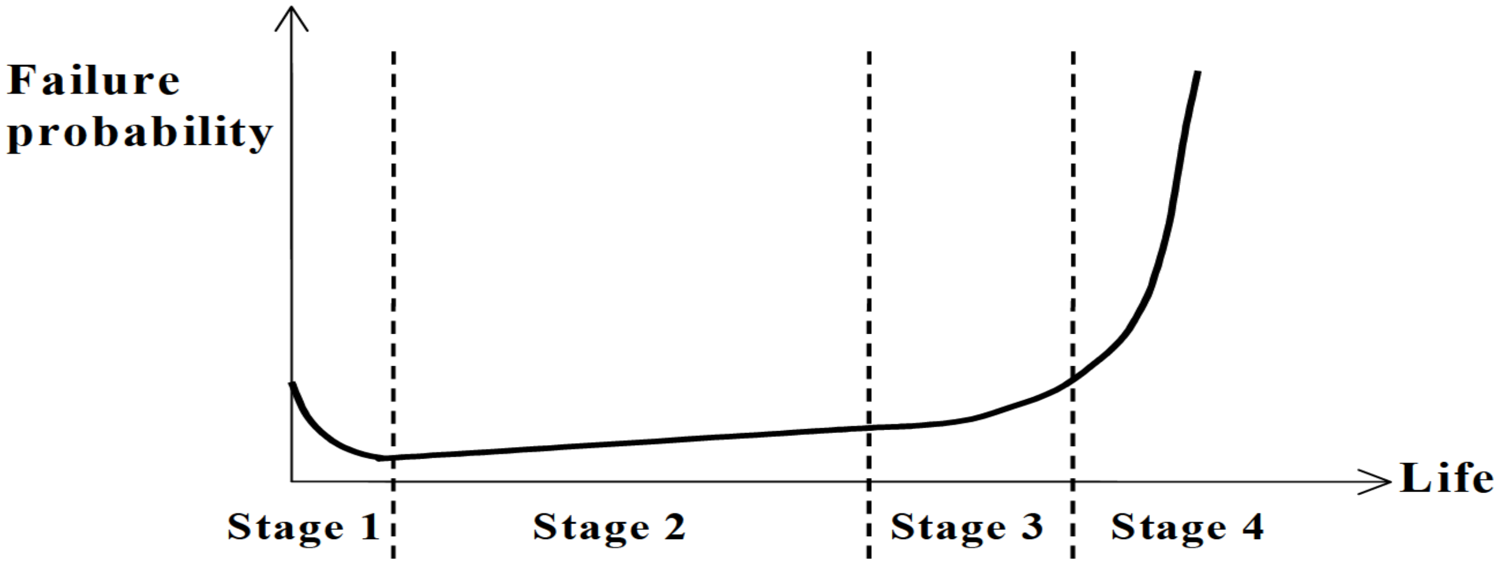
Figure 4b Defects detected by SAFed inspections of all equipment types in 4 years

Effect of periodic maintenance, inspection and repair on the risk of failure for a piece of equipment.



Each saw-tooth represents an inspection being carried out

Model for the probability of failure of a population of equipment



Stage 1: Post Commissioning ('Initial').
Stage 2: Risk-Based ('Maturity').
Stage 3: Deterministic ('Ageing').
Stage 4: Monitored ('Terminal').

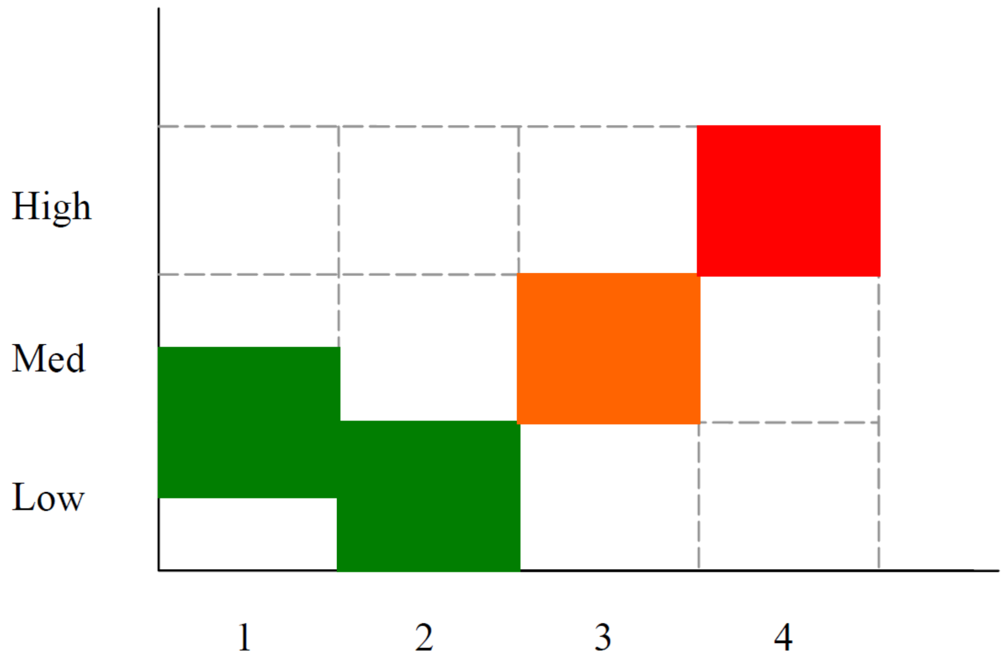
Description of the four stages of progressive ageing

STAGE1	POST COMMISSIONING (INITIAL)	• Design and manufacturing faults • Installation issues (bolting, valves, leaks) • Commissioning issues (over/under filling) • Early life operating faults (training, trials) • Shake-down • Identification of potential ageing sites • First thorough examination (forger-print) • Reducing rate of problems
STAGE2	RISK-BASED (MATURITY)	• Operation well within design limits • Retained corporate knowledge of design, manufacture • Ageing damage not yet significant: • Routine maintenance • Extended operating periods • Selected inspection. by risk analysis. to confirm expectation of slow degradation • Updated risk analysis from experience • Rate of damage low and predictable
STAGE3	DETERMINISTIC (AGEING)	• Design limits approaching • Evidence of active deterioration • Repairs. refits. modifications • Changes in process/use • Lack of full history/corporate memory • Changes in ownership: second hand plant • Quantitative NDT inspection to measure extent and rate of damage accumulation • FFS assessment required for life extension • Degradation rate increasing - less predictable
STAGE4	MONITORED (TERMINAL)	• Accelerating and accumulating damage • Beyond design limits and known operating experience • Approaching safe operating limits • Advanced inspection and FFS required to determine residual life • Decreasing intervals between inspections • Monitoring • Major repairs and refits replacement needed • End of life based on costs of repairs or replacement and wider economic factors

材料損傷型式

- Wall thinning.
- Stress-driven damage, cracking and fracture.
- Physical deformation.
- Metallurgical / environmental damage.

Approach To Inspection Strategy Over The Four Stages Of Equipment Life



Stage 1 - Confirmatory - first thorough (finger-print/benchmark) inspection
Stage 2 - Confirmatory - risk-based inspection
Stage 3 - Deterministic - quantitative inspection
Stage 4 - Deterministic - monitoring inspection

Methods of inspection for the detection of various damage mechanisms

Ageing damage	Example degradation mechanism	NDT methods/techniques used for detection/assessment
Blisters	Defective coating	(1)
	Hydrogen absorption	(6), (9), (11) & (12)
Scaling (boiler tubing)	Precipitation	(1)
Blockages (piping)	Various (internal) e.g. fouling	(17), (18), (21) & (26)
Cavitation	Creep damage	(31)
Cracking	Corrosion fatigue	(1), (6), (9), (11), (12), (17) & (23)
	Creep damage	(1), (3), (6), (9), (11) & (12)
	Fatigue	(1), (2), (3), (4), (6), (7), (8), (9), (11), (12), (17) & (23)
	Hydrogen absorption	(6), (9), (11) & (12)
	Stress corrosion	(1), (2), (3), (4), (6), (9), (11), (12), (17) & (23)
Dents/gouges	Various (external) e.g. impact damage	(1)
Embrittlement	Hydrogen absorption	(6), (9), (11) & (12)
Fretting wear	Vibration	(1), (4) & (30)
Holes	Various (internal/external) e.g. local corrosive attack	Vessels/tanks: (1), (2), (4), (14) & (27) Piping: (1), (2), (4), (17) & (26) Tubing: (1), (4), (15), (16) & (17)
Wall thinning (general)	Corrosion	General: (1), (6), (10), (13), (17), (20), (23) & (25) Tubing: (4), (15), (16) & (17)
Wall thinning (local)	Corrosion Corrosion under insulation (CUI)	General: (1), (10), (17), (18), (19), (20), (21), (23), (24) & (25) Pitting (small): (1), (2), (10), (17) & (23) (4), (15), (16) & (17) Tubing Pitting (large): (1), (10), (17), (19), (20), (21), (23), (24) & (25) (19), (20), (21) & (22)
	Erosion	Pipe bends (6), (10), (13), (17), (20), (24) & (25) Weld root (6), (9), (11), (12) & (17) Tubin2(4), (15), (16) & (17)

Main NDT methods:	Specialist NDT techniques:	Screening techniques:	Other techniques:
(1) Visual Inspection — may include use of magnification and endoscopes	(7) Alternating Current Field Measurement (ACFM)	(18) Thermography	(26) Acoustic Ranger
(2) Penetrant Testing	(8) Alternating Current Potential Difference (ACPD)	(19) Long Range Ultrasonics	(27) Leak Testing
(3) Magnetic Particle Testing	(9) Time of Flight Diffraction (TODF)	(20) Pulsed Eddy Current	(28) Strain Gauging
(4) Eddy Current Testing	(10) Ultrasonic Corrosion Mapping	(21) Real-time Radiographic Imaging	(29) MAPS
(5) Radiographic Testing	(11) Automated Ultrasonic Pulse-echo	(22) Neutron Backscatter	(30) Vibration Measurement
(6) Ultrasonic Testing	(12) Ultrasonic Phased Array	(23) Acoustic Emission (AE)	(31) Metallographic replication
	(13) Ultrasonic Continuous Monitoring	(24) Magnetic flux leakage	
	(14) Spark Testing	(25) Saturation low frequency eddy current (SLOFEC)	
	(15) Internal rotary inspection system (IRIS)		
	(16) Remote field eddy current (RFEC)		
	(17) Remote visual inspection (RVI)		

適用性(缺陷)評估與殘餘壽命(老化)評估

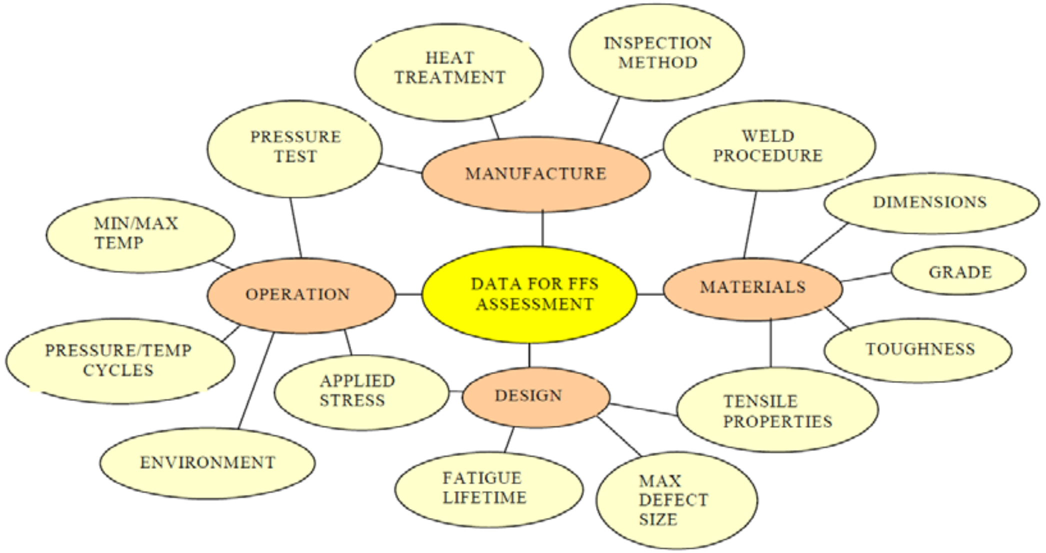


Figure 7 Data required for carrying out fitness-for-service assessment

API 579	BS 7910
Intended for equipment designed using the ASME code and materials and gives results consistent with the original ASME design safety margins. May be used for equipment designed to other codes but users should be prepared to interpret the procedures in an appropriate manner.	Applicable to all metallic structures and materiak and is written in a more generalised manner without reference to a particular industry, design code or material thereby allowing users to decide safety margins.
Covers a wide range of damage types typically found in refining and petrochemicals application, and gives procedures for different types of metal loss, physical damage, low and high temperatures, and crack like defects.	Deals comprehensively with fatigue and fracture of flaws in and around welded joints and gives annexes covering advanced aspects such as mismatch, mixed mode loading, residual stress effects and leak before break.
Designed at level 1 for use by plant inspectors and engineering personnel with the minimum amount of information from inspection and about the component. Levels 2 and 3 are for use by professional engineers.	BS 7910 requires some technical expertise in fracture mechanics and access to fracture parameter solutions and toughness data at all levels.

Process Map for the Management of Equipment Ageing

Integrity awareness and culture (Section 1)

- What pressure systems and or containers of hazardous fluid are on site?
- Who is responsible for this equipment?
- What consideration is given to equipment ageing and life extension?

↓

Management of ageing assets (Section 2)

- What company strategies or policies are in place for managing ageing?
- What records/documentation about the equipment are maintained?
- Can your company demonstrate it has the competencies required?
- What provisions are in place for the retention and use of corporate knowledge?

↓

Identification and control of ageing (Section 3)

- Does the plan/`equipment have a retirement date?
- How well is the equipment lifecycle blown?
- How aware is your company of the indicators of ageing?
- Does the approach to inspection take account of the stage of equipment life?

↓

Addressing ageing through assessment and remediation (Section 4)

- What options are considered when ageing related damage is detected?
- How is fitness-for-service assessed for aged components and components where the remanent life is uncertain?
- What procedures are used in the event that equipment requires repair?
- What procedures are in place regarding revalidation of equipment?
- Do written schemes of examination reflect the equipment's age and condition?
- What policies are in place for determining the end of equipment life?

資產完整性管理的預警訊號

- 已知防護措系統故障，仍操作繼續
- 設備檢驗過期
- 安全閥校驗過期
- 沒有正式的維護程序
- 採用運轉到失效的理念
- 延遲維護計畫直到下一個預算週期
- 減少預防性維修來節省開支
- 已損壞或有缺陷的設備未被標記並且仍在使用中
- 多次且重複出現的機械故障
- 設備腐蝕和磨損明顯
- 洩漏頻發
- 已安裝的設備和組件不符合工程設計規範
- 允許設備和組件的不當使用
- 用消防水冷卻工藝設備
- 沒有徹底解決警報和儀表管理存在的問題
- 旁路警報和安全系統
- 工廠在安全儀表系統停用的情況下運行，並且未進行風險評估和變更管理
- 關鍵的安全系統不能正常工作或沒有經過測試
- 虛驚擾報警的和聯鎖停車
- 缺乏設備風險管理
- 在運轉的設備上進行作業
- 臨時的或不合標準的維修普遍存在
- 預防性維護不連貫
- 設備維護紀錄不是最新的
- 維護計劃系統長期存在問題
- 在設備缺陷管理方面沒有正式的程序
- 維護工作沒有徹底關閉

RECOGNIZING CATASTROPIC INCIDENT WARNING SIGNS IN THE PROCESS INDUSTRIES, ccps