Ageing Management for the Full Life Cycle of NPPs

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Contents

1 A glance of China nuclear power plants

■ Up till now, the mainland of China has **38** NPP units in operation and **18** units under construction .

■ All NPP units, either in operation or under construction, are in sea coast, the most developed area and relatively remote from coal mine areas

■ Nuclear power is approximately 3% of the total energy power.

■ Chinese Government promised in 2015 in Paris Agreement on Climate Change that by the year 2030, the percentage of non-fossil energy in China should reach as high as 20%,

Conclusion : Nuclear power is an irreplaceable choice to reduce greenhouse gas and to realize clean energy, however, we need strengthening the cost-benefit of NP.

Qinshan -1, 320 MWe PWR, the 1st NPP unit in mainland of China, started operation in Dec. 15, 1991

1 A glance of China nuclear power plants - a list of operating NPPs

NPP	Owner	Type	Power(MWe)	FCD (1st unit)	Date of connecting to grid (1st unit)
Qinshan 1	CNNC	PWR	310	1985-03-20	1991-12-15
Daya Bay	CGN	PWR	2x984	1987-08-07	1993-08-31
Qinshan 2	CNNC	PWR	2x650+2x660	1996-06-02	2002-02-06
Ling'ao	CGN	PWR	2x990+2x1086	1997-05-15	2002-02-26
Qinshan 3	CNNC	CANDU	2x728	1998-06-08	2002-11-19
Tianwan	CNNC	WWER	2x1060+1x1126	1999-10-20	2006-05-12
Ningde	CGN	PWR	4x1086	2008-02-18	2012-12-28
Hongyanhe	CGN/SPIC	PWR	4x1119	2007-08-18	2013-02-17
Yangjiang	CGN	PWR	4x1086	2008-12-16	2013-12-31
Fuqing	CNNC	PWR	4x1089	2008-11-21	2014-08-20
Fangjiashan	CNNC	PWR	2x1089	2008-12-26	2014-11-04
Fangchenggang	CGN	PWR	2x1086	2010-07-30	2015-10-25
Changjiang	CNNC	PWR	2x650	2010-04-25	2015-11-07

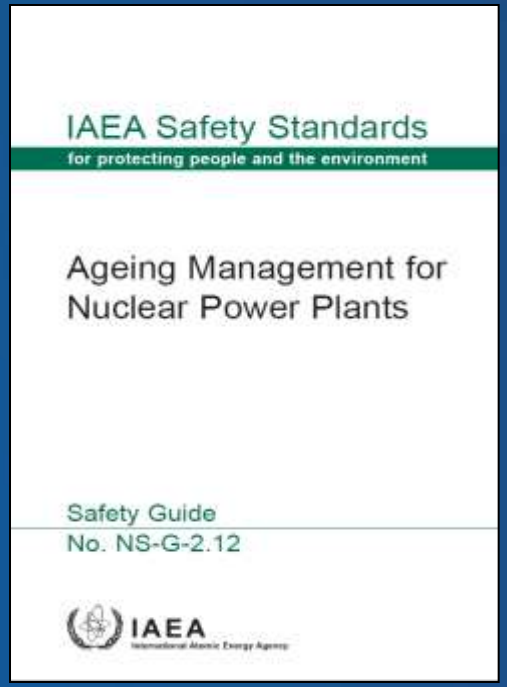
1 A glance of China nuclear power plants - a list of NPPs under construction

NPP	Owner	Type	Power（MWe）
Hongyanhe	CGN/SPIC	PWR	2x1119
Fuqing	CNNC	PWR（Hualong 1)	2x1089
Yangjiang	CGN	PWR	2x1086
Sanmen	CNNC	PWR（AP1000）	2x1250
Haiyang	SPIC	PWR（AP1000）	2x1250
Taishan	CGN	PWR（EPR）	2x1750
Fangchenggang	CGN	PWR（Hualong 1）	2x1080
Shidaowan	CHNG	HTR-PM	1x200
Tianwan	CNNC	WWER , PWR	1x1126、2x1089
Total			20752/18

Contents

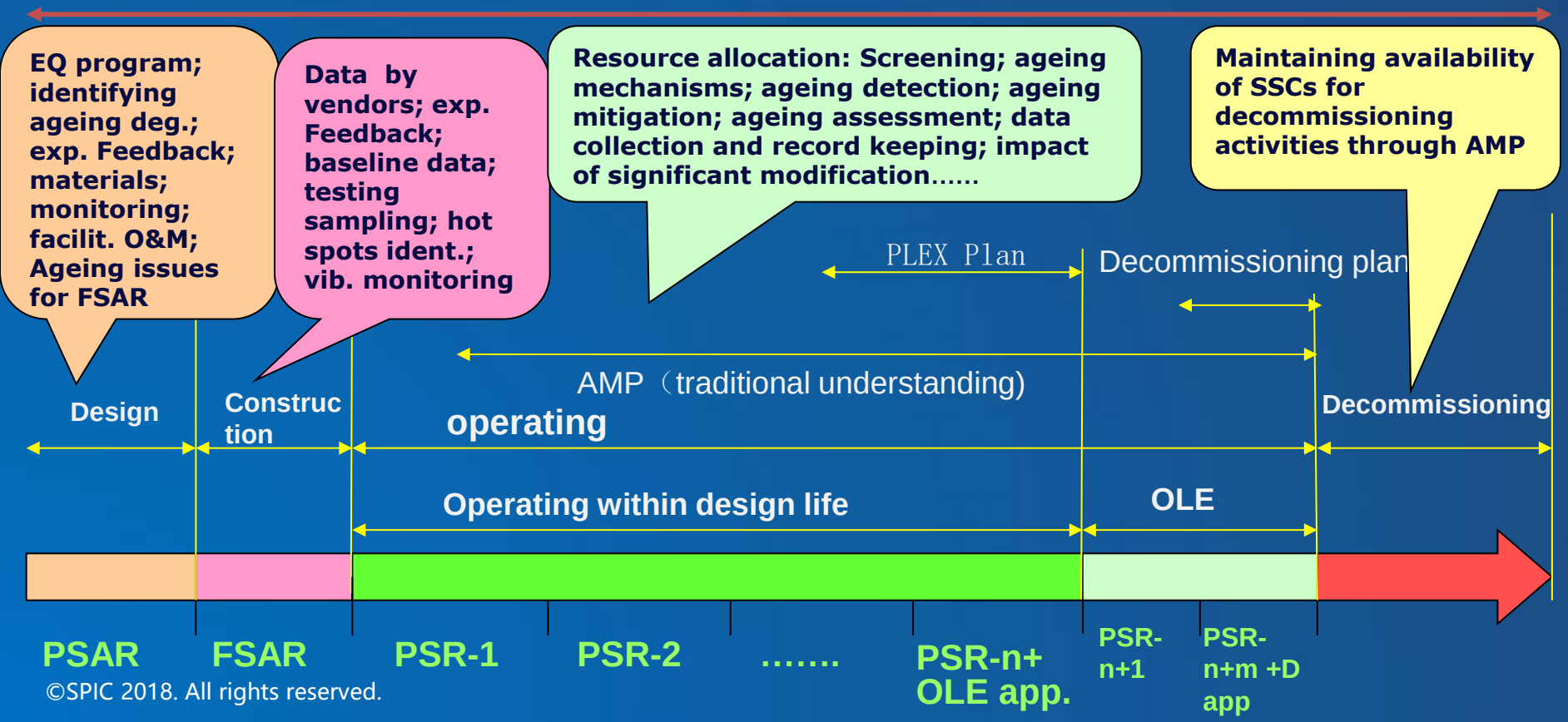
2 Safety aspects of NPPs' full life cycle of AM

- In 2009 IAEA published a guidelines on "Ageing Management for Nuclear Power Plants" (NS-G-2.12), introducing concept of proactive AM.
- AM is not only required for operating stage, but also required for full life cycle stages of NPPs, including design, fabrication, construction, commissioning and decommissioning.
- In 2012, NNSA published safety guideline Ageing management for NPPs (HAD 103/12) based on the IAEA guideline NS-G2.12.



2 Safety aspects of NPPs' full life cycle of AM

Reliability starts from design and is maintained throughout the full life cycle of NPP



2 Safety aspects of NPPs' full life cycle of AM

Stage	Needs	Activities arouse from needs	Related technical support
Design	EQ programme	1) Design basis conditions for normal operation and DBA; 2) EQ requirements and document package	EQ activities based on design requirements to demonstrate qualification of all safety related equipment
	Identify and evaluate potential ageing mechanisms	A series of ageing mechanisms analysis reports as part of design documents	Analysis of potential ageing mechanisms based on material properties, environment conditions and loadings
	Experience feedback	Comprehensive experience feedback report based on an effective coordinative mechanism	Failure analysis when necessary
	Online monitoring	To sensible ageing mechanisms, online monitoring should be considered in design	Establishment of various monitoring systems
	Facilitate of inspection and maintenance	Compromise of construction schedule and facilitation of O&M	Demonstration of accessibility and capability of maintenance
	As a special topic for Final Safety Analysis Report (FSAR)	Explain AMP policies, EQ requirements, condition monitoring measures to safety regulatory during design stage	A series of additional technical support documents for FSAR

EQ Activities throughout whole life of NPPs

Design input

- Identifying PIEs
- Environmental conditions
- Safety functions.
- Equip. list

EQ Implementation

- EQ Requirements and criteria, methodologies
- Programmes and procedures, QA…
- Identifying resources
- EQ implementation by test, analysis or the combination.
- Documentation

Maintaining EQ

- Control of maintenance
- Control of change
- Environment monitoring
- Degradation and failure analysis
- Experience feedback

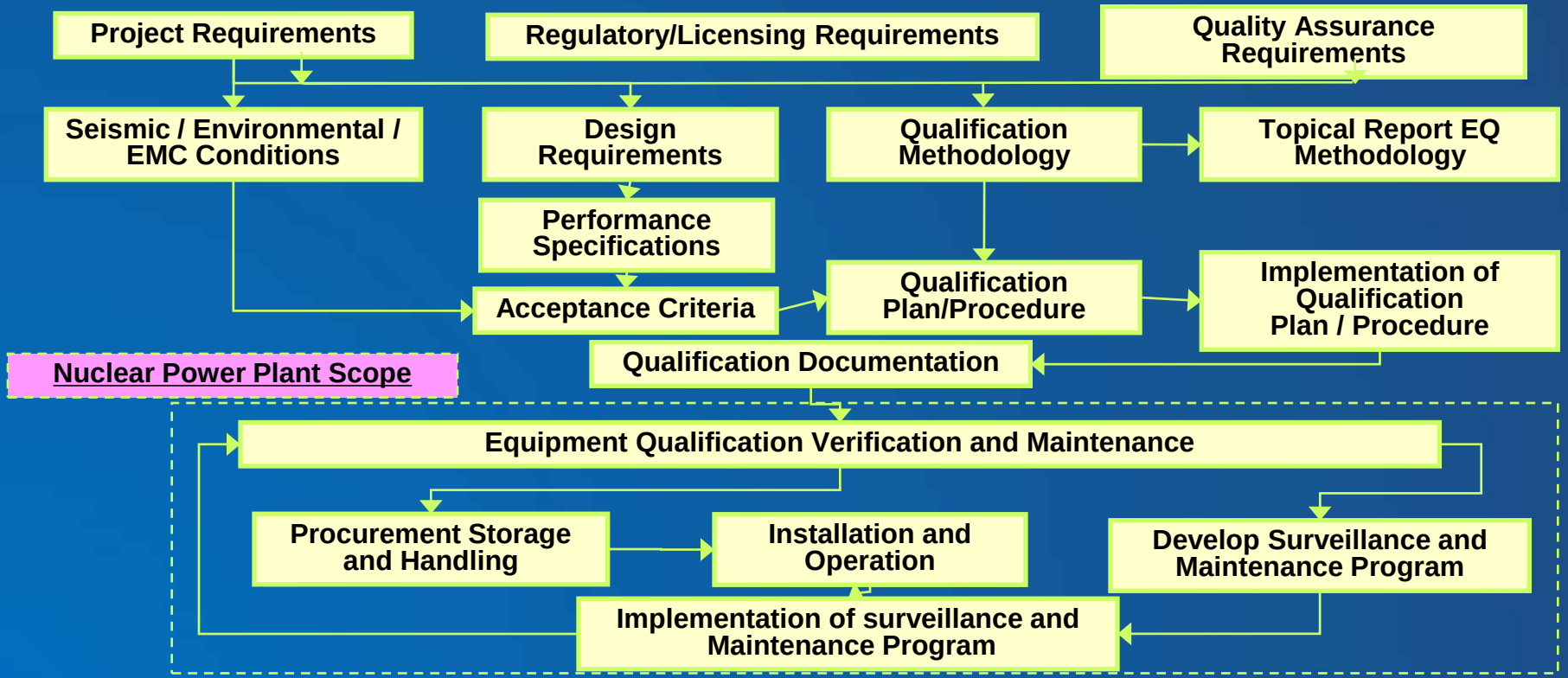
Feedback

Design and Construction stage

Operation stage

2 Safety aspects of NPPs' full life cycle of AM

Equipment Qualification Flowchart



2 Safety aspects of NPPs' full life cycle of AM

Stage	Needs	Activities arouse from needs	Related technical support
Fabrication/ Manufacture	Ageing effects being sufficiently taken into account in fabrication	1) Conveying ageing related factors to suppliers by purchaser; 2) In fabrication, ageing effects and related mitigation measures being sufficiently taken into account; 3) Designers may provide technical support regarding ageing analysis	Experiments on material properties; simulation of fabrication process; defect assessment; tolerance analysis; ageing mitigation measures
	Baseline data collection and documentation	1) Baseline data being well kept and submitted to purchaser; 2) baseline data list and record keeping requirements provided by designer	Baseline specifications; database technique
	Sufficient specimen used for ageing monitoring and evaluation based on design specifications	Surveillance and monitoring requirements given in design specifications by designer and followed by suppliers	Specimen program and utilization plans, such as RPV surveillance program

2 Safety aspects of NPPs' full life cycle of AM

Stage	Needs	Activities arouse from needs	Related technical support
Commissioning	Systematic program as guideline for measuring and record keeping for ageing management related baseline data	In commissioning program, ageing management related data measuring and record keeping requirements should be brought into and implemented	Specific data needed, methodology on measurement and record keeping, acceptance criteria
	Special attention for identification of temperature and irradiation hot spots and for measurement of vibration on piping and rotating components	Systematic investigation on hot spots; vibration measurement for safety related piping and rotating components; advanced record keeping systems	Identification of vibration limits; establishment of baseline for trend analysis
	Baseline data are properly collected under critical conditions which are in conformance with design requirements. Installed equipment is in conformance with its EQ requirements.	Technical support materials be ready by operator for safety review; site reconfirmation being carried out during commissioning	For qualified equipment, carrying out walk down on site to reconfirm during commissioning

2 Safety aspects of NPPs' full life cycle of AM

Stage	Needs	Activities arouse from needs	Related technical support
Operation	Overall AMP	Determination of AMP policies and resource allocation for related activities	SSC screening; ageing mechanism analysis;
	For any significant changes, ageing effects should be evaluated	Ageing effects to safety should be demonstrated for significant changes	It should be demonstrated by TLAA that under new conditions of the changes, ageing effects has no significant impact to safety.
	For any new discovered ageing mechanisms, assessment should be performed in time	Ageing mechanism analysis based on current knowledge and experience feedback	Analyze that the effects to safety by the new ageing mechanisms can be effectively controlled
	Pre-arranged plan being prepared based on experience feedback on significant ageing	Establishment and implementation of component or topic specific AMPs	The AMPs should include ageing mechanism analysis, ageing evaluation, inspection, mitigation, etc.
	Spare parts management	Availability of spare parts and stock reservation method	Demonstrate the availability of replacement parts

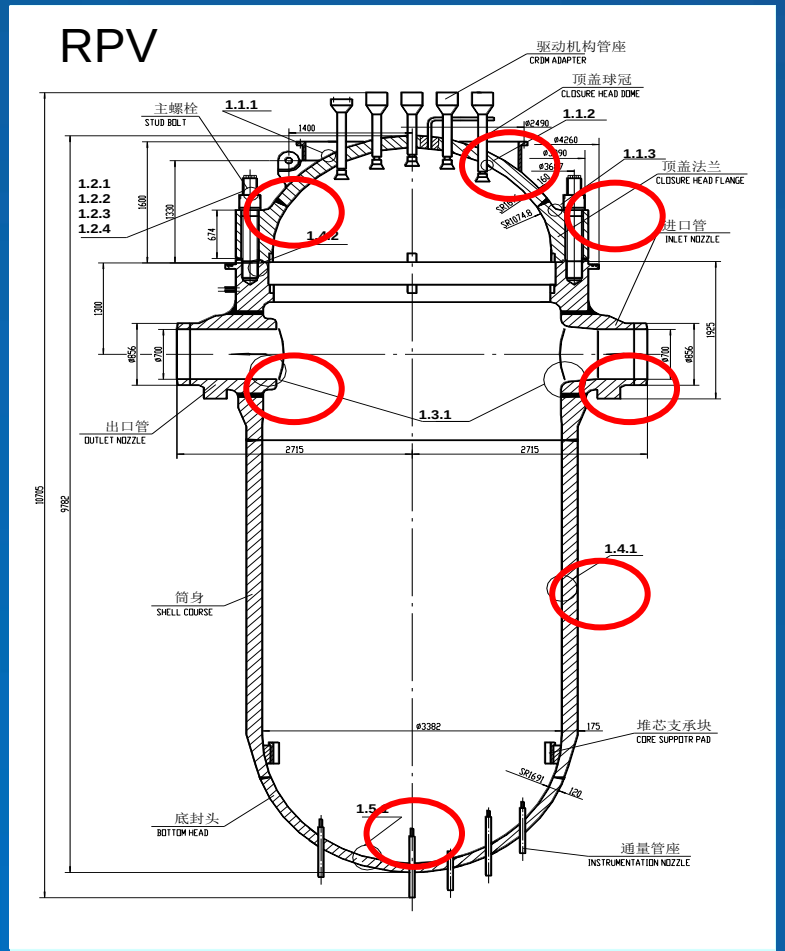
Significant ageing mechanisms - Reactor Pressure Vessel

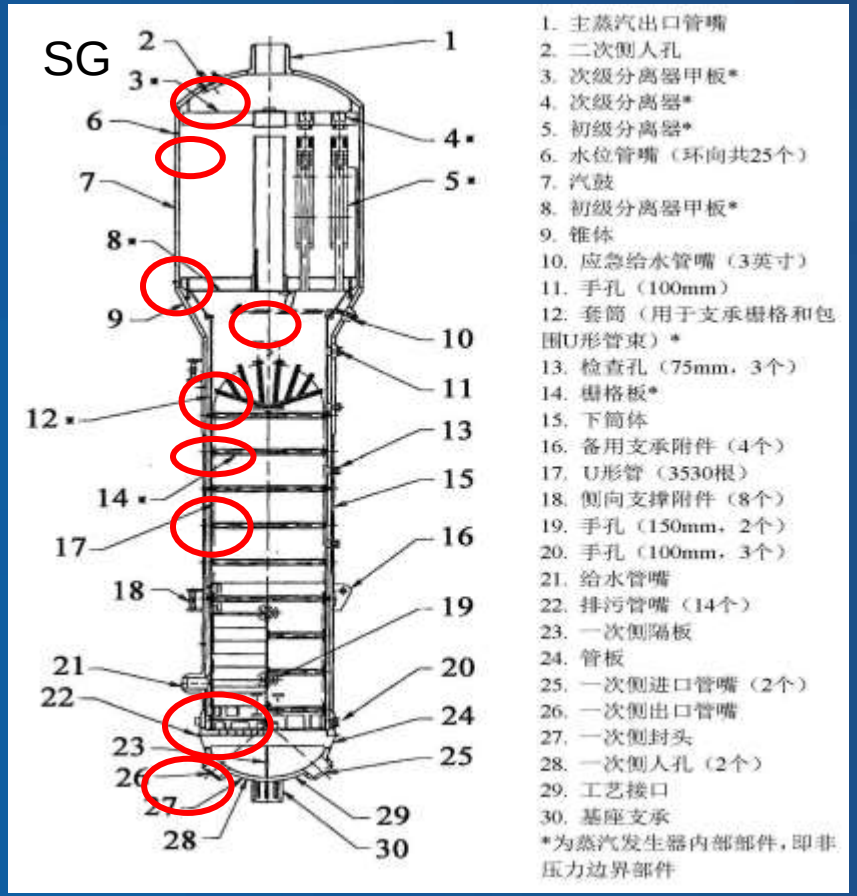
Degradation Locations	Corrosion	Fatigue	Irradiation	Fretting and Wear
Core beltline region		environment fatigue	neutron irradiation	
Stud bolts	boric acid corrosion	mechanical and thermal fatigue		
Nozzle corner		mechanical and thermal fatigue		
CRDM penetration	PWSCC	mechanical and thermal fatigue		
Out surface of head	boric acid corrosion			
Bottom head				wear induced by loose parts

Significant ageing mechanisms - Steam Generator

Degradation Sites	Erosion-Corrosion	Fatigue	Irradiation	Fretting and Wear
Tube to tubesheet crevices	ODSCC			
Tube to support plate crevices	ODSCC			
Sludge pile	ODSCC			
Free span region of tubes	ODSCC			
Contact region between tubes and anti-vibration bars				
Contact region between tubes and loose parts				fretting-wear
Feedwater nozzle, nozzle to piping welds	erosion-corrosion	high and low cycle fatigue		fretting-wear
Shell girth welds	SCC	Corrosion-fatigue		
Feedwater nozzle bore, blend radius, shell inside surface beneath the nozzle		high-cycle fatigue		
J-tubes and feedring	erosion-corrosion			

2 Safety aspects of NPPs' full life cycle of AM





Significant ageing mechanisms - Reactor Internals

Degradation Sites	Erosion-Corrosion	Fatigue	Irradiation	Fretting and Wear
Core barrel		thermal stress, FIV	neutron irradiation	
Formers and baffles		Thermal stress	irradiation swelling	
Bottom-mounted instrumentation		FIV		fretting wear
Guide tube assembly		FIV		fretting wear
Radial keys		FIV		fretting wear
Instrumentation sleeve, control rod guide tube		FIV		wear
Irradiation surveillance capsule		FIV	neutron irradiation	fretting wear
Connections (bolts, pins)	IGSCC, IASCC	FIV	irradiation creep and swelling	
Compressed elastic ring		Axial forces		

2 Safety aspects of NPPs' full life cycle of AM

Significant ageing mechanisms - other primary loop components

Component	Erosion-Corrosion	Fatigue	Embrittlement	Fretting and Wear
Pressurizer (spray nozzle)		thermal fatigue		
RCP (rotating parts)		vibration		
Charging pump (rotating parts)		vibration		
Pressurizer safety valve		thermal stratification	thermal ageing of CF8M material	mechanical vibration
Electric gate-valve		thermal stratification	thermal ageing of CF8M material	mechanical vibration
Main piping		thermal/ mechanical fatigue	thermal ageing	
Surge line of pressurizer		thermal/ mechanical fatigue		Vibration
Class 1E Cable	oxidation and chemical corrosion		thermal ageing/ irradiation embrittlement	vibration
transformer		cyclic operation	thermal ageing	

Significant ageing mechanisms - Containment and structures

Structures	Corrosion	Fatigue	Embrittlement	Concrete degradation
Concrete	acidic or alkaline corrosion	fatigue		Leaching and efflorescence
Reinforced concrete	General corrosion or pitting of reinforced steel		Temperature increase near reactor cavity	
Pre-stressing system	Denting, stress corrosion or hydrogen embrittlement			Loss of prestressing
Steel lining	Corrosion induced by anti-rust failure			

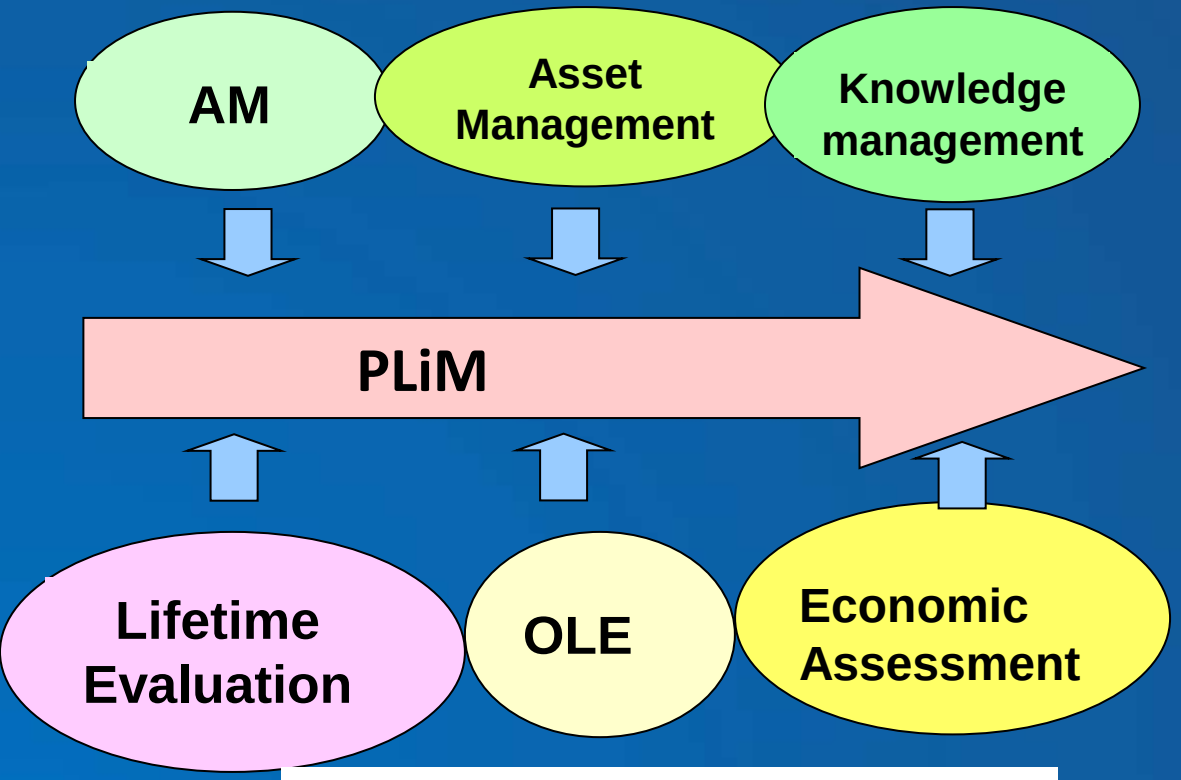
2 Safety aspects of NPPs' full life cycle of AM

Stage	Needs	Activities arouse from needs	Related technical support
Decommissioning	Decommissioning activities should be carried out through effective ageing management	SSCs important to decommissioning should be maintained their availability and functionality through effective ageing management	Analyze functionality of aged SSCs which are important to decommissioning

2 Safety aspects of NPPs' full life cycle of AM – PLiM: economic considerations

- **The targets of NPP PLiM lie in:**
  - Maintaining high safety level
  - Optimizing SSCs' operation, maintenance and service life
  - Maintaining acceptable SSCs' performance status
  - Obtaining as much as possible the return on investment beyond NPP lifetime
  - Establish basis for LTO of NPP

2 Safety aspects of NPPs' full life cycle of AM – PLiM: economic considerations



Relation between AM and PLiM

Ageing Management:

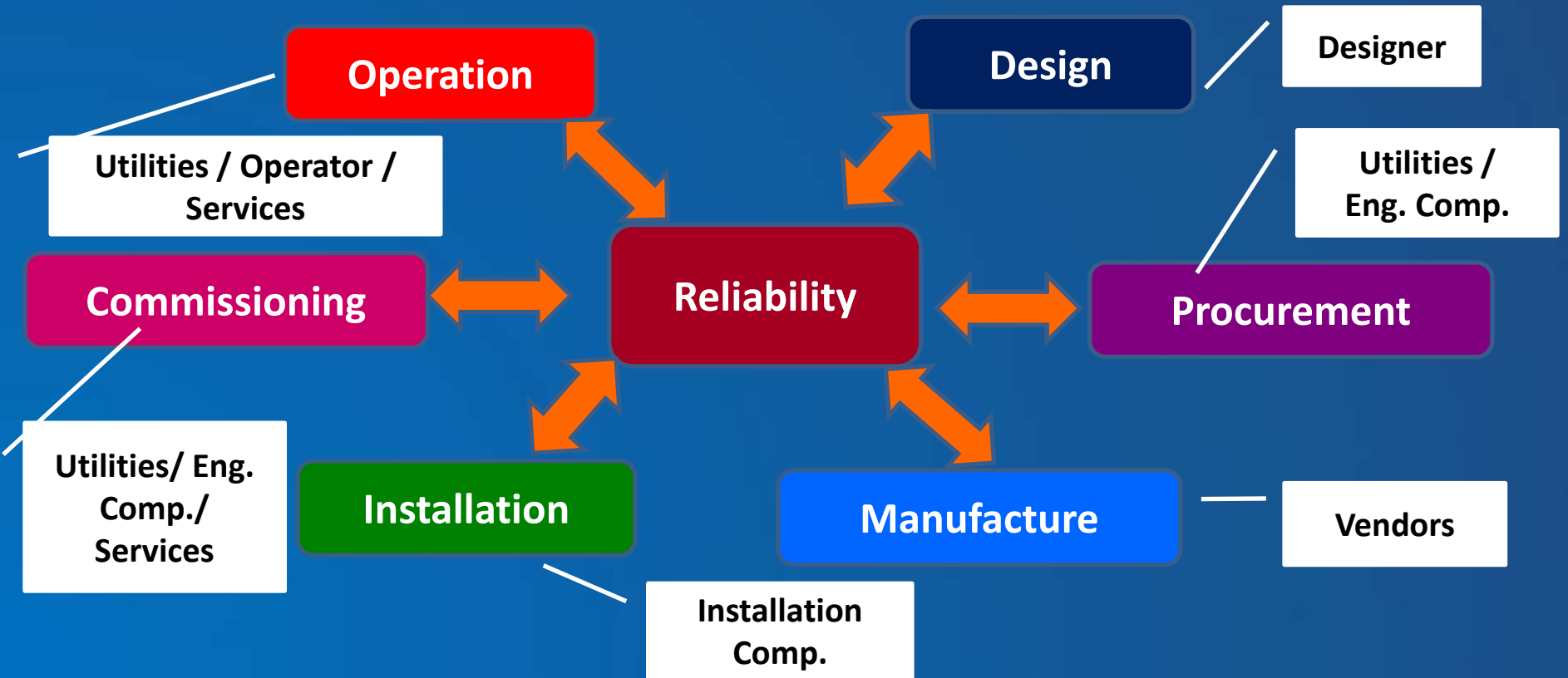
- More focus on safety
- Limited to safety related SSCs

PLiM:

- Economic, more from whole plant
- 2nd Loop SSCs included
- Asset Management
- Knowledge Management

2 Safety aspects of NPPs' full life cycle of AM

- Challenges on Management - Although ultimate responsibilities belong to utilities, how to distribute them to related parties?



I. A glance of China nuclear power plants

II. Safety aspects of NPPs' full life cycle of AM

III SNPTC's practice

3 SNPTC's Practice

Establishment of SNEQC in collaborated by SPERI，SNERDI，SNPEC，SNPAS etc. to meet the needs of EQ for CAP series NPPs

3 SNPTC's Practice

SNEQC – Seismic/vibration shake tables

2.5m*2.5m 3 axis 6 freedom Seismic table

1.5m*1.5m high frequency shake table

1 m*1 m 3 axis 6 freedom Seismic table

3 SNPTC's Practice

SNEQC – LOCA facilities

Fig. 1-LOCA facilities

Fig. 2-LOCA facilities (large cabin)

LOCA simulating facilities	L: 24 m**3	Maximum Temperature rate more than 130℃/s
	M: 14.7 m**3	
	S: 7.1 m**3	

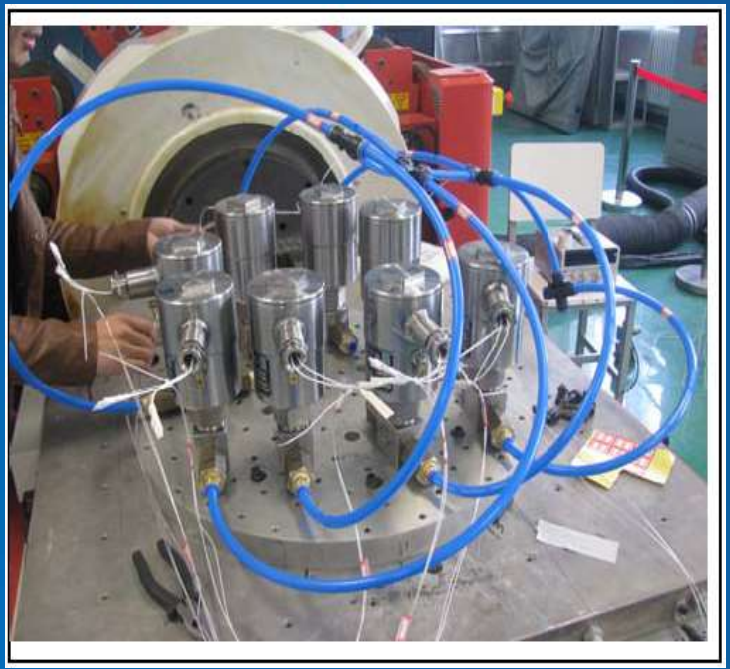
3 SNPTC's Practice

Electric Penetration Assembly (EPA) EQ implementation

- 2013.4.27 — •EQ program review
- 2013.12 — • EMC
- 2014.3 — • Electric shortcut test
- 2014.4 — • Seismic test
- 2015.1 — • LOCA test
- 2015.3 — • Completion of EQ reports

3 SNPTC's Practice

R&D on EQ fundamental aspects implemented by SNERDI



The Seismic margin test for electric-magnet valve

The activation energy measurement for non-metallic material

3 SNPTC's Practice

IAEA CRP on cable ageing study

Benchmark, Condition Monitoring

- **Thermal ageing**
- **Radiation ageing**
- **Thermal-Radiation interaction**

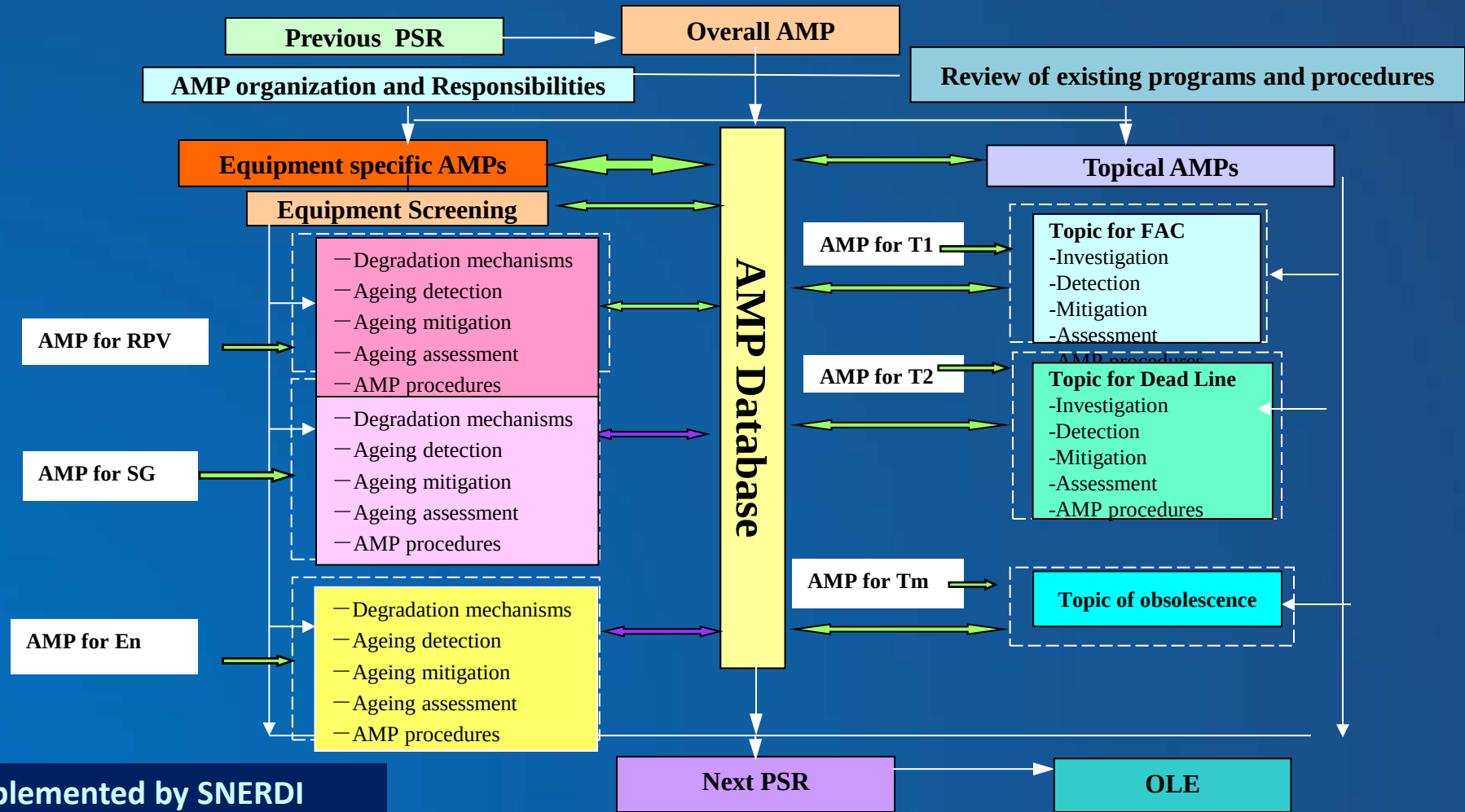
Implemented by SNERDI

Thermal (**AMS and others**)

Irradiation Cell (AECL)

Irradiation Thermobox (UJV)

3 SNPTC's Practice – Overall AMP



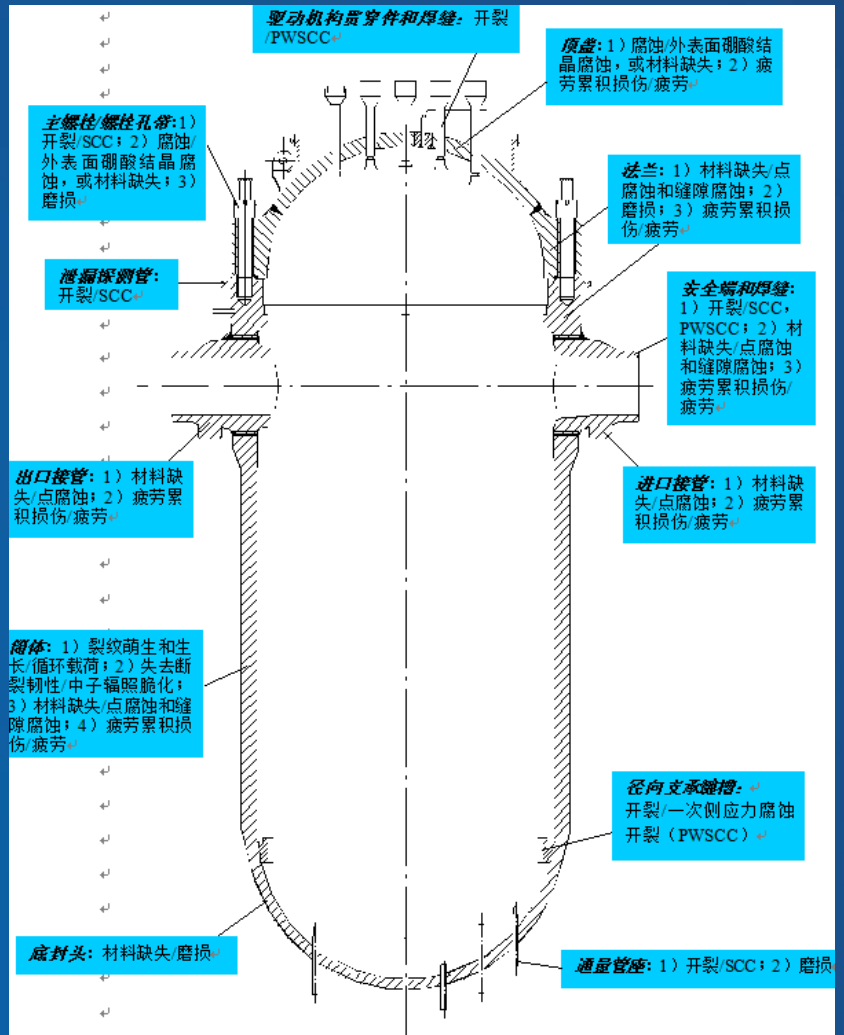
Implemented by SNERDI

3 SNPTC's Practice – RPV AMP

- main targets:

- **Ageing Mechanism Analysis**
- **AMP development**
- **Structure of AM Data Base**
- **RPV life assessment considering PTS condition**

Implemented by SNERDI



3 SNPTC's Practice – RI AMP

Reactor Internals AMPs development for PWRs of Qinshan NPP

Qinshan-I 1 x 320 MWe PWR unit

Qinshan-II 4 x 650 MWe PWR units

Entrusted by CNNO, SNERDI carried out AMP development for Qinshan-I and Qinshan-II (2013~2015)

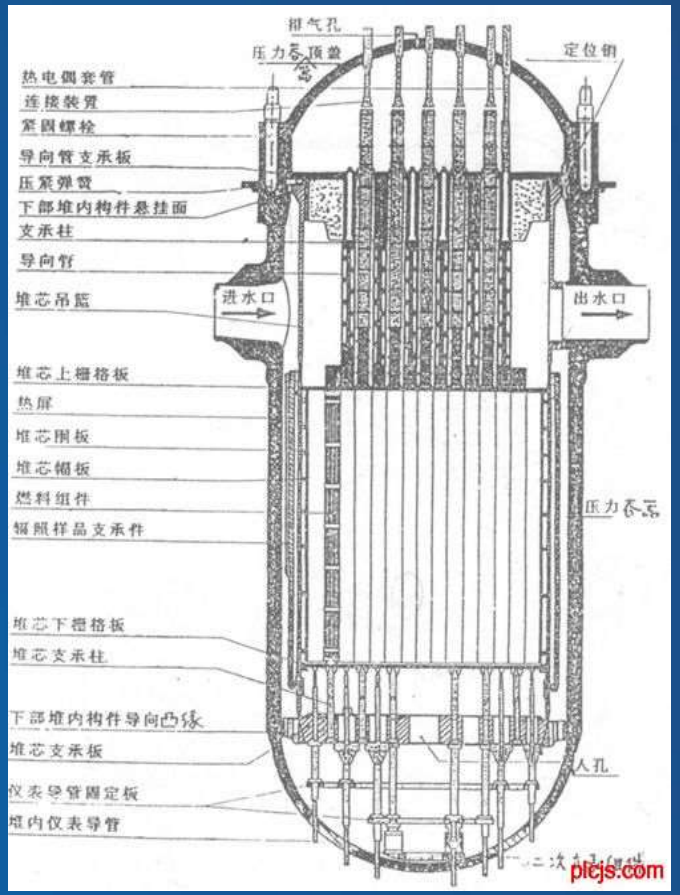
3 SNPTC's Practice – RI AMP

Reactor Internals AMPs development for PWRs of Qinshan NPP

➢ ***Evaluation on RI ageing mechanisms***

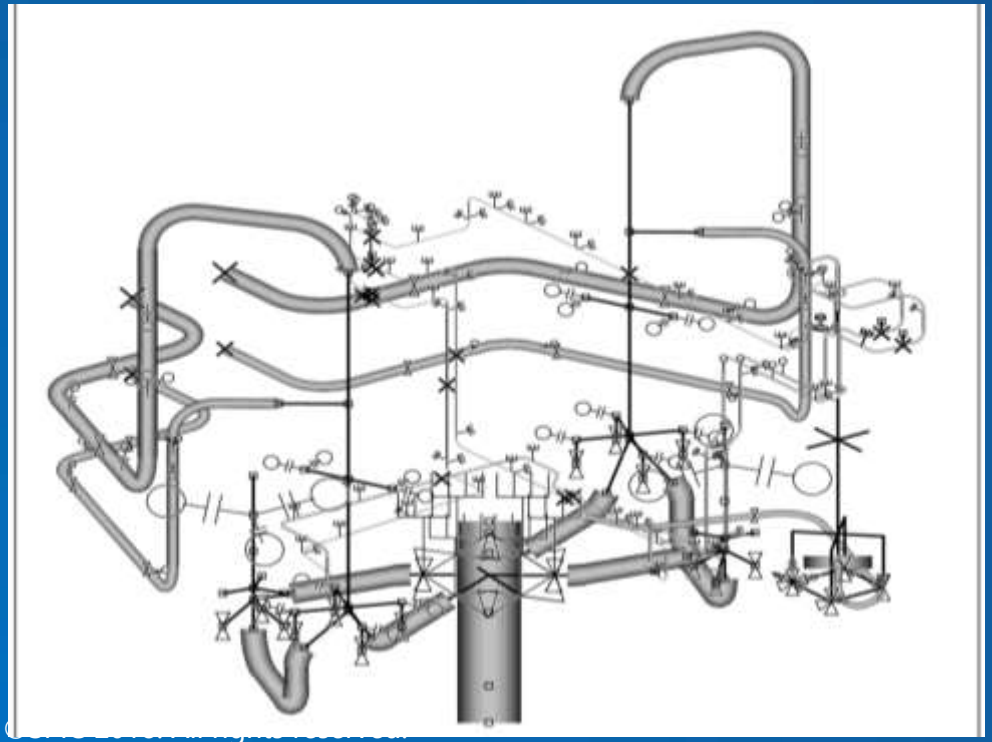
- Fatigue
- Irradiation embrittlement
- Wear
- Stress relaxation
- Stress corrosion cracking (SCC)
- Irradiation-assisted stress corrosion cracking (IASCC)
- Void swelling
- Thermal ageing embrittlement

Implemented by SNERDI



3 SNPTC's Practice – AMP for Piping Systems

PWR Primary Boundary Piping System AM Research for Qinshan NPP -- Qinshan-I and Qinshan –II, carried out by SNERDI

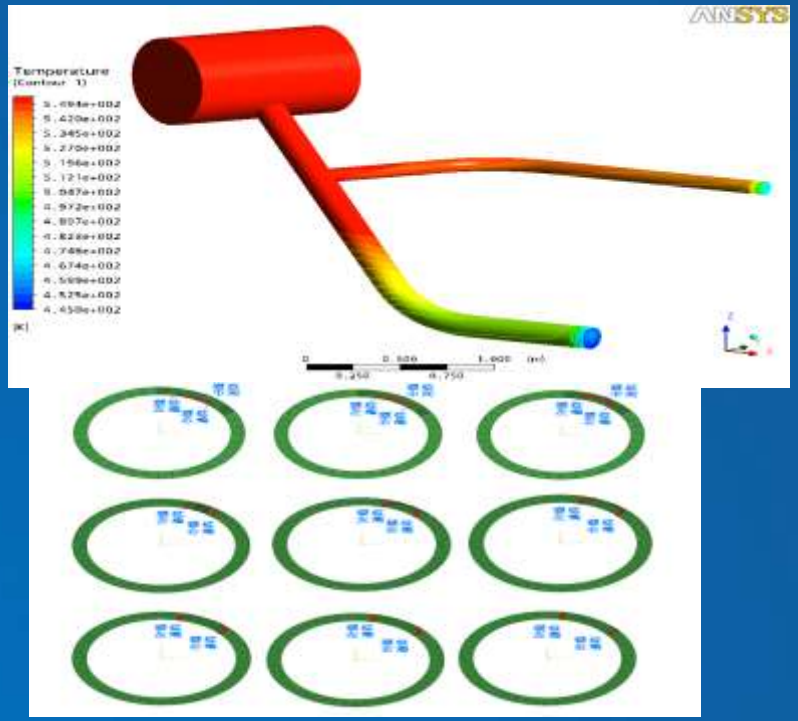


Main tasks:

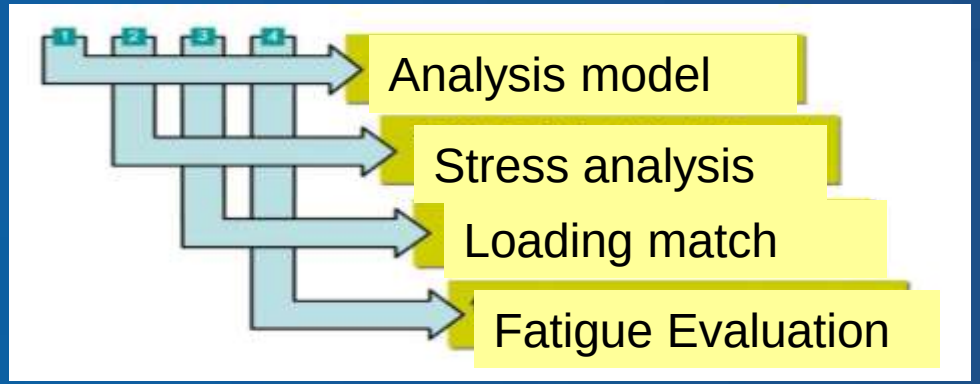
- Ageing Mechanism Analysis
- Aging Condition Assessment Guide Line
- Structure of AM Data Base
- Aging Condition Evaluation and Remaining Life Evaluation
- Primary Boundary Piping System AMP -- General
- Primary Boundary Piping System AMP – Unit Specific
- Technical Guideline for Primary Boundary Piping System AM Evaluation

3 SNPTC's Practice – AMP for Piping Systems

PWR Primary Boundary Piping System AM Research for Qinshan NPP



- **Examples of Ageing Analysis**
  - **Thermal Stratification**
  - **Crack Growth**
  - **Fatigue**



Implemented by SNERDI

3 SNPTC's Practice – Ex-vessel Neutron Dosmetry

Daya Bay NPP Ex-Vessel Neutron Dosimetry

- **The Ex-Vessel Neutron Dosimetry (EVND) was installed in one of units of Daya Bay NPP in October 19th 2013**
- **Data from EVND provide best estimation of RPV neutron exposure together with data from RPV surveillance capsules and calculated neutron fluence, which can be used in following aspects:**
  - **Assess the neutron embrittlement of RPV**
  - **monitor the change of neutron fluence rate and spectrum after modification of core design and reactor internals**
  - **Provide data for RPV aging management and life extension of NPP**

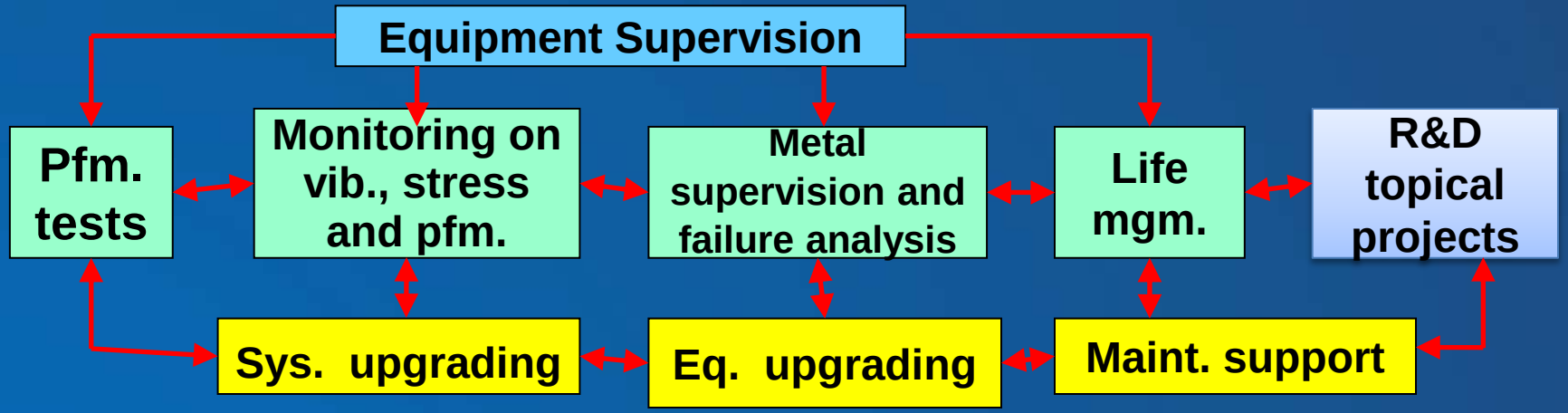
Crew of EVND installation in Daya Bay NPP

Implemented by SNPSC

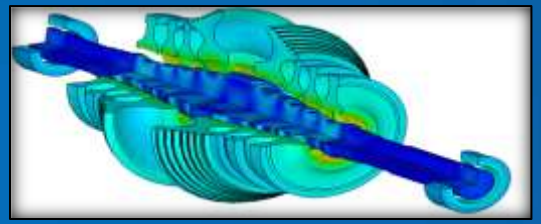
3 SNPTC's Practice – Life Management for CI

Implemented by SPERI

Life management for conventional island



Overall Target: Digital plant, good economy, high reliability, good safety performance and well under control



3 SNPTC's Practice – OLE for Qinshan-1

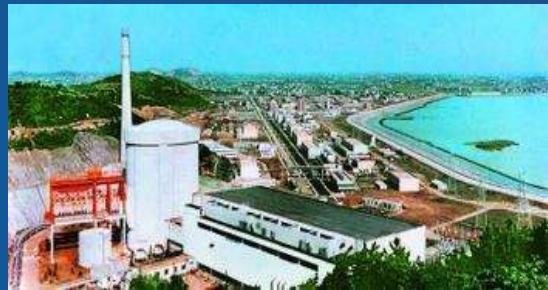
Implemented by SNERDI

- 2013.7 OLE Program proposal submission
- establishment
- 2014.9 Program group
- 2014.12 Scoping and screening
- 2015.12 IPA and environmental impact evaluation
- 2016.6 FSAR and TLAA
- 2016.12 OLE application submission
- 2017 ~ 2022 NNSA review
- Promise execution
- 2021.12 OLE permission
- 2014.1 OLE Program proposal acceptance

2013 | 2014 | 2015 | 2016 | 2017 | 2020 | 2021

R18 (2018.4 ~ 2019.4)

R19、R20



Summaries

- Activities on ageing management cover the full life cycle of NPPs, including stages of design, manufacture, construction, commissioning, operation, as well as decommissioning.

- Although the ultimate responsibilities belong to utilities, the responsibilities should be distributed to all related parties to make sure ageing management being implemented and the related records being well kept.

- SNPTC carried out ageing management activities and provided comprehensive services in all life cycle stages of NPPs.

Thank you for your attention