AGEING MANAGEMENT METHODOLOGY

Module 3

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General approach to management of NPP ageing

Three basic steps:

Selecting/screening NPP components in which ageing should be evaluated

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Performing ageing management (AM) studies for the selected components to determine appropriate AM actions

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Taking AM actions based on results of these studies and plant specific data for AM

Structure of Module 3

- Session 3.1:
  Screening of NPP components for AM studies/evaluations

- Session 3.2:
  Methodology for AM studies/evaluations
  - Phase I: Interim AM study
  - Phase II: In-depth AM study

- Session 3.3:
  Data collection and record keeping for AM

Screening of NPP components for AM studies/evaluations

Session 3.1

Resource document: Methodology for Ageing Management of NPP Components Important to Safety, Technical Report Series No. 338 (1992)

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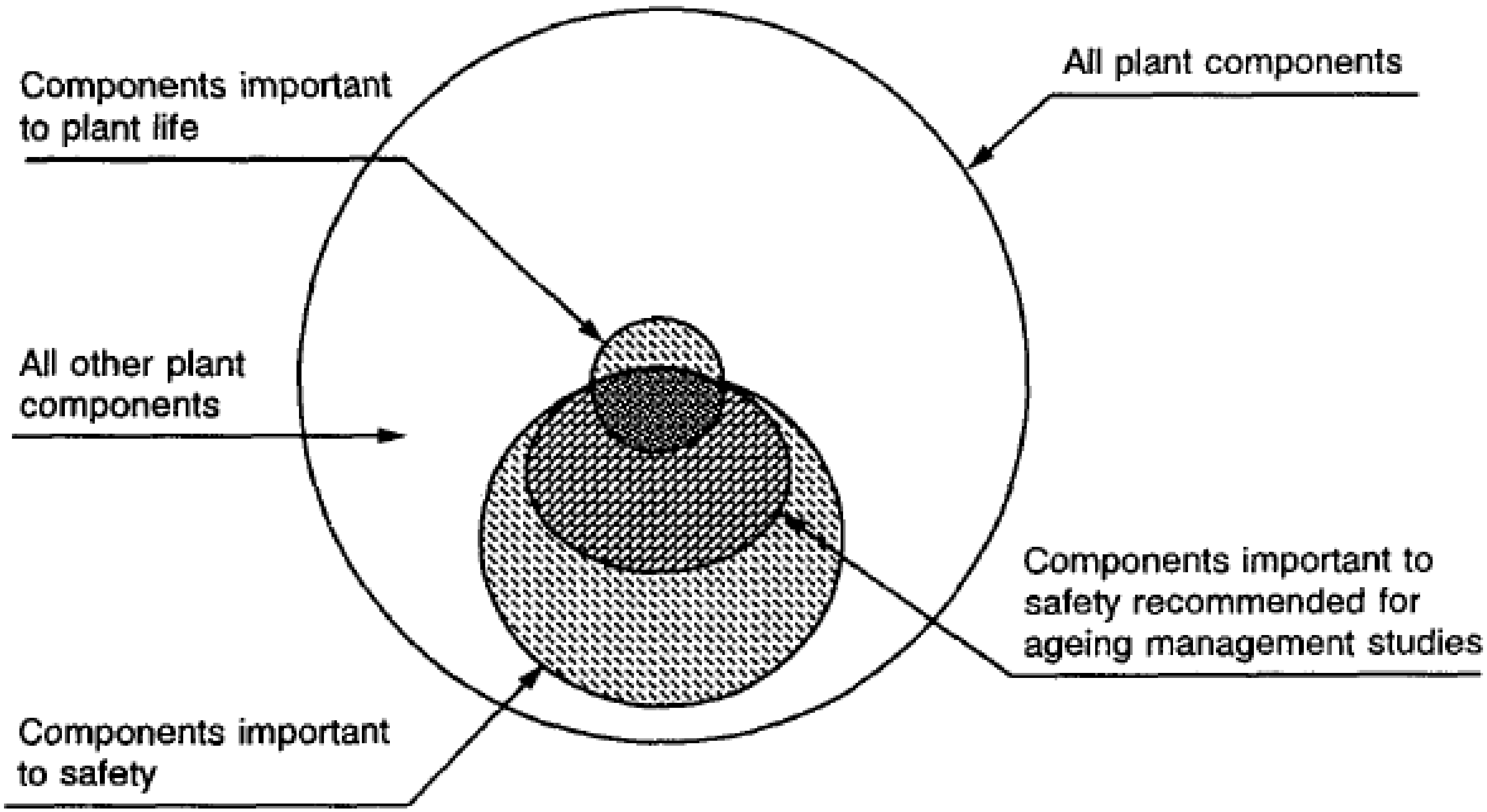
Back Ground

NPP has thousands of different components all of which are affected to some degree by ageing

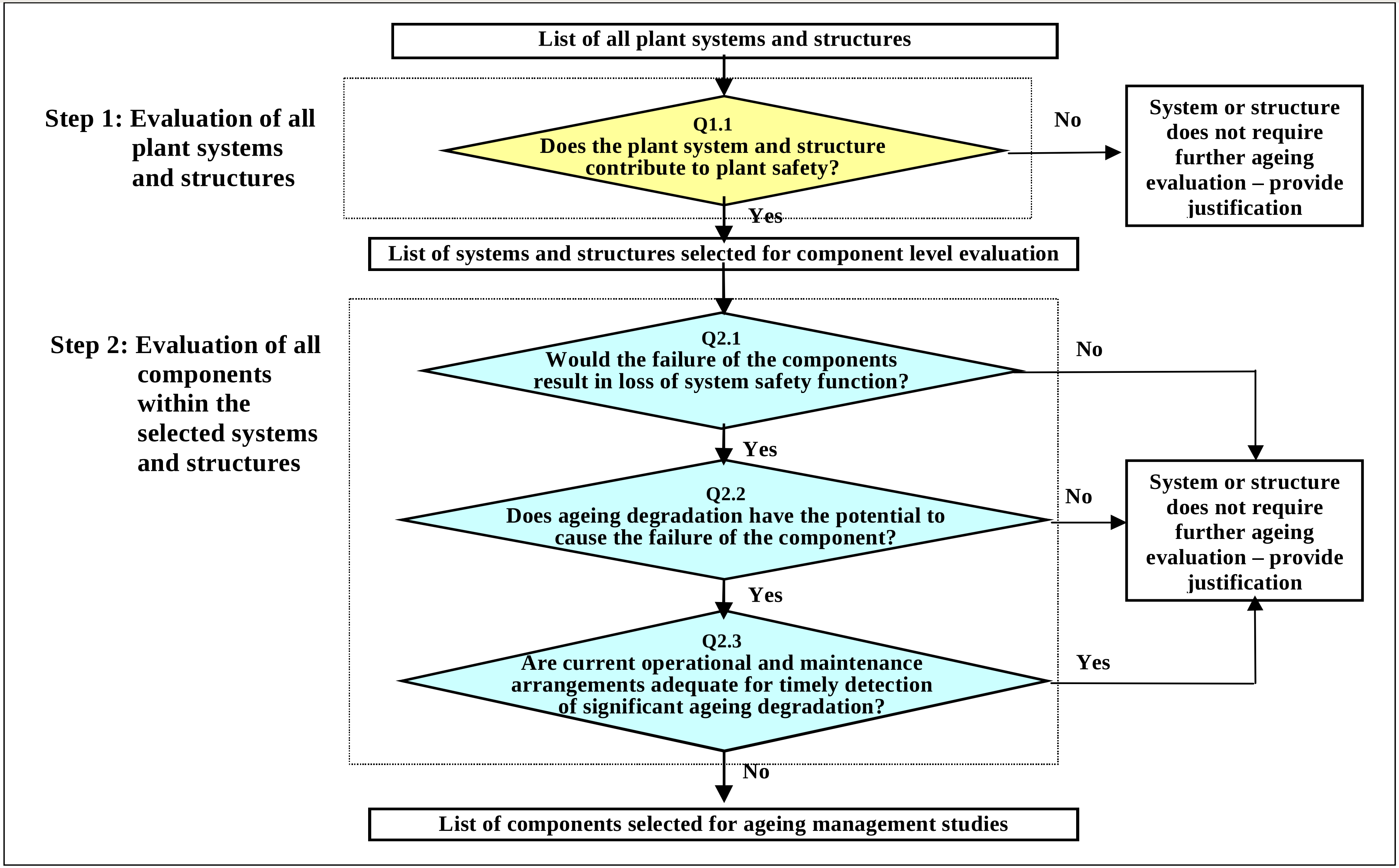
It is not necessary to evaluate ageing of individual components

A systematic screening process can identify a manageable number of NPP components whose ageing should be evaluated

Grouping of NPP components for AM



Selection process for safety important NPP components for ageing management studies



Step 1 screening: at the system and structure level

***Question 1.1:* Does the plant system or structure contribute to plant safety?**

- Review a list of all NPP systems and structures
- Use existing safety classification system and/or PSA of an NPP

Output of Step 1 *– a shorter list of systems and structures to be evaluated at component level*

Step 2 screening: at component level

***Question 2.1:* Would component failure result in a loss of system safety function?**

- Consider significance of component failure that could be caused by ageing degradation
- Screen out components if they do not contribute to the performance of a safety function
- Include components whose failure could prevent other SSCs form performing safety functions
- Include both redundant and diverse components as ageing is a common cause mechanism and diversity may not protect against all ageing effects

Step 2 screening: at component level (Cont'd)

Question 2.2: *Does ageing degradation have the potential to cause component failure?*

- Consider component's susceptibility to age related failure taking into account:
  - *significance of known ageing mechanisms*
  - *all applicable operating experience*

Step 2 screening: at component level (Cont'd)

***Question 2.3:* Are current operational and maintenance arrangements adequate for timely detection of significant ageing degradation?**

- Consider availability and adequacy of condition indicators to detect and predict component's ageing degradation
- Consider adequacy of existing techniques to monitor these condition indicators
- Consider adequacy of existing operating and maintenance practices to mitigate component's ageing degradation

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Step 2 screening: at component level (Cont’d)

Output of Step 2

– *list of components for AM studies arranged in generic groups*

Categorizing Criteria: (1)Type	Categorizing Criteria: (2)Fluid	Categorizing Criteria: (3)Material	Name (Number)	Specification (Capacity× Pump Head)	Selecting Criteria: Importance	Selecting Criteria: Condition: Operation	Selecting Criteria: Condition: Maximum Pressure (MPa)	Selecting Criteria: Condition: Maximum Temperature (℃)	Selection	Cause
Vertical Shaft Type Mixed Flow Pump	Sea Water	Stainless Steel	Auxiliary Sea Water Pump (3)	1420 m^3/h× 45.7 m	MS-1	Continuously	approx. 0.5	38	◎	Importance Operation
			Containment Cooling Service Water Pump (4)	456 m^3/h× 167 m	MS-1	Occasionally	approx. 1.9	52		
			Circulating Water Pump (2)	44200 m^3/h× 13 m	※	Continuously	approx. 0.5	38		
	Pure Water	Cast Steel	Condensate Pump (3)	1360.8 m^3/h× 220 m	※	Continuously	approx. 3.1	149	◎	
Horizontal Shaft Type Centrifugal Pump	Pure Water	Stainless Steel	Clean Up Auxiliary Pump (1)	181.8 m^3/h× 115.8m	PS-2	Continuously (short time)	approx. 8.3	302	◎	Importance
			Clean Up Recirculation Pump (2)	91.2 m^3/h× 802 m	※	Continuously	approx. 8.3	302		
		Carbon Steel	High Pressure Coolant Injection Pump (1)	681.6 m^3/h× 853.4m	MS-1	Occasionally	approx. 13.8	204	◎	Importance Pressure
			Reactor Feed Water Pump (3)	1360.8 t/h× 811 m	※	Continuously	approx. 13.8	205		
			Control Rod Drive Pump (2)	14.28 m^3/h× 1159m	※	Continuously	approx. 12.1	93		
			Condensate Transfer Pump (2)	56.8 t/h× 54.9m	MS-2	Continuously (short time)	approx. 1.6	66		
	Cooling Water	Cast Steel	Reactor Building Closed Cooling Water Pump(3)	442.8 m^3/h× 45.7 m	MS-1	Continuously	approx. 0.7	66	◎	Importance
			Turbine Building Closed Cooling Water Pump(3)	770 t/h× 45.7m	※	Continuously	approx. 0.7	52		
Vertical Shaft Type Centrifugal Pump	Pure Water	Carbon Steel	Shut Down Cooling Pump (2)	465 m^3/h× 45.7 m	MS-1	Continuously (short time)	approx. 8.3	302	◎	Operation
		Carbon Steel	Core Spray Pump (4)	283.2 m^3/h× 200 m	MS-1	Occasionally	approx. 3.5	172		
			Containment Cooling Service Water Pump (4)	363.3 m^3/h× 100.2 m	MS-1	Occasionally	approx. 1.7	80		

Prioritization of components for AM studies

- Limited resources, Special desire to deal with components of high safety significance
  ⇒ require prioritization of components
- Basic deterministic approach considers:
  - Consequences of component failure
  - Some components must not fail, e. g. an RPV
  - Susceptibility to ageing degradation
  - Effectiveness of existing AM programme
  - Component’s replaceability
  - Expected component service life
- Hybrid deterministic-probabilistic approach can use insights form a plant specific PSA

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Methodology for AM studies/evaluations

Session 3.2:

Resource document: Methodology for Ageing Management of NPP Components Important to Safety, Technical Report Series No. 338 (1992)

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Methodology for AM studies

1. Can be used for:
   - AM studies of generic component types
   - ageing assessments of specific plant components
   - both components important to safety and components important to production.

2. Individual AM studies address:
   - Understanding ageing
   - Monitoring ageing
   - Mitigating ageing

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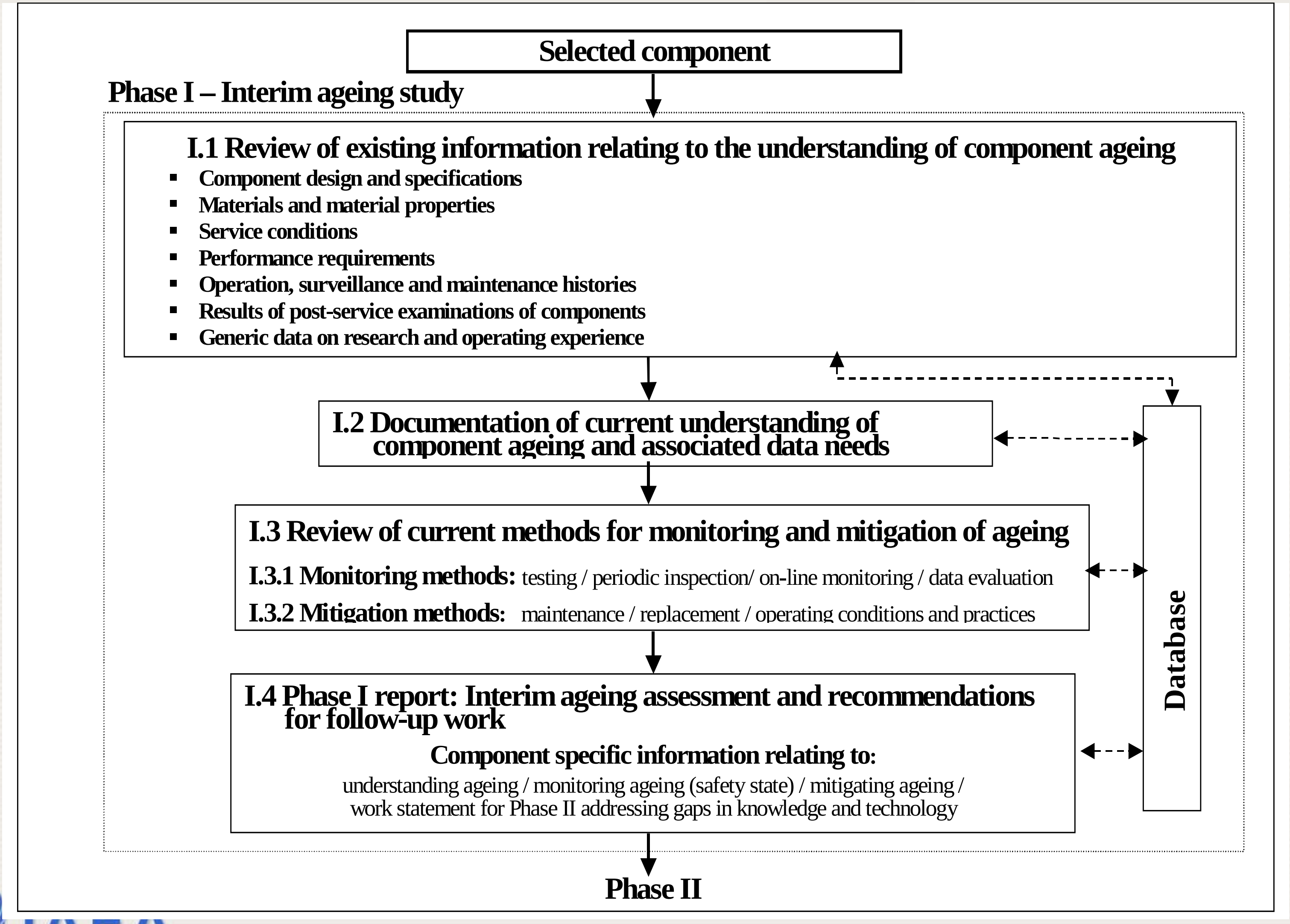
Phased approach to AM studies

- **Phase I, Interim ageing study**
  - focused on the review and evaluation of existing knowledge, technology and practices
- **Phase II, Comprehensive ageing study**
  - deals with knowledge and technology gaps identified in Phase I.

Phase I: Interim ageing study



Review of existing information relating to the understanding of component ageing

- Understanding of component ageing is necessary for effective monitoring and mitigation of ageing effects
- It consists of the knowledge of significant ageing mechanisms and effects which is related to:
  - component’s design
  - materials
  - service conditions
  - performance requirements
  - operating experience and relevant research results

Review of existing information relating to the understanding of component ageing (Cont'd)

- **Components' design** - review and summarize
  - **Design documentation**
  - **Specifications**
  - **Standards**
  - **Operating and maintenance manuals**
  - **Product literature**

Review of existing information relating to the understanding of component ageing (Cont'd)

- **Materials** – obtain information on
  - **Significant parts and materials**
  - **Parts and materials susceptible to ageing**
  - **Manufacturing process**
  - **As-built & after-service condition**
  - **Heat treatment**
  - **Types of polymers & activation energies**

TABLE I. TYPICAL RVI MATERIALS

Component	Standards and specifications		
	US type reactors (ASTM, ASME)	French type reactors (RCC-M, AFNOR)	German type reactors (KTA 3204)
Upper support forging	SA-182 Grade F304	Z2CN 19-10 N controlled (M 3302)	X6CrNiNb18-10 (1.4550)
Hold down spring	SA-182 Grade F403 (mod) or SA-182, Grade F304	Z2CN 19-10 N controlled (M 3301)	Inconel X-750
Core barrel nozzles	SA-182, Grade F304	Z2CN 19-10 N controlled (M 3301)	X6CrNiNb18-10 (1.4550)
Lower support forging	SA-182, Grade F304	Z2CN 19-10 N controlled (M 3302)	X6CrNiNb18-10 (1.4550)
Radial keys	SA-182, Grade F304	Z2CN 19-10 N controlled (M 3301)	X6CrNiNb18-10 (1.4550)
Radial keys/hard facing	SA-182, Grade F304/Stellite	Z2CN 19-10 N controlled (M 3301)	Alloy 600/Stellite 6 or 1.4550/ hard faced
Core barrel	SA-240, Type 304	Z2CN 19-10 N controlled	X6CrNiNb18-10 (1.4550)

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Review of existing information relating to the understanding of component ageing (Cont'd)

➢ Service conditions

Identify environmental, loading and power conditions resulting from normal operation (incl. expected transients), testing, shutdown and storage; accident and post-accident conditions for relevant components.

- **Temperature, radiation, humidity, chemicals**
- **Mechanical loadings**
- **Electrical loadings**
- **System chemistry**

TABLE VIII. OPERATING CONDITIONS FOR WESTERNPWR RVI

Plant component	Temperature [°C]	Fluence		
		10^{21} n/cm^2		dpa
		E >0.1 MeV	E >1 MeV	
US 900 MW NPP				
Core barrel	–	18	6.9	12
Core baffle	–	160	74	110
Formers	–	18–160	7–74	12–110
Bolts	–	160	74	110
Upper core plate	–	0.43	0.22	0.3
Lower core plate	–	6.2	3.2	4.6
French 900 MW NPP				
Core barrel	286–20	14	7	9.6
Core baffle	290–370	109	54	80
Formers	290–370	13–76	6–38	10–56
Bolts	300–370	82	41	58
Upper core plate	–	0.5	0.25	0.3
Lower core plate	–	3–8	1.5–4	2–5.6

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Review of existing information relating to the understanding of component ageing (Cont'd)

Performance requirements

- Assess whether ageing could impair component's ability to perform its safety functions
- Identify condition and functional indicators suitable for detecting ageing degradation and predicting future performance

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Review of existing information relating to the understanding of component ageing (Cont'd)

- **Operation, surveillance and maintenance histories**
  - Review records of NPP surveillance, maintenance, ISI, design change and reliability data, and national/international databases on significant events and equipment reliability to obtain information on:
    - **Component failure rate**
    - **Failure mechanisms**
    - **Degradation sites (locations)**
    - **Age related failure modes and causes**

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Review of existing information relating to the understanding of component ageing (Cont'd)

- **Results of component post-service examination**
  - To confirm information on ageing mechanisms and effects deduced from historical records
    - **review results of tests and examinations of components removed from service, and**
    - **if not available, perform screening type in-situ tests and visual examinations**
- **Generic research and operating experience data**
  - Review information from national, international and NPP owners groups programmes on component ageing, e.g. IAEA, OECD/NEA, EC, EPRI for additional insight into relevant ageing phenomena.

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Documentation of current understanding of component ageing

- Data set containing results of the above reviews
- Summary describing current understanding derived from the data set
  - **Materials, service conditions, ageing mechanisms, ageing effects, and degradation sites**
  - **Explanatory notes and references**
- Component data needs for
  - **ageing assessment and management**

More details in Session 3.3.

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Review of current methods for monitoring and mitigation of component ageing

- Performed in the light of the current understanding of component ageing

Monitoring methods

- **Assess effectiveness of currently used functional and condition indicators for timely detection of component ageing degradation**
- **Assess capability of existing monitoring methods (inspection, testing, and on-line monitoring) to measure these indicators**
- **Assess existing data evaluation techniques and criteria for detecting degradation and predicting future performance of the component**

Review of current methods for monitoring and mitigation of component ageing (Cont'd)

- **Mitigation methods**

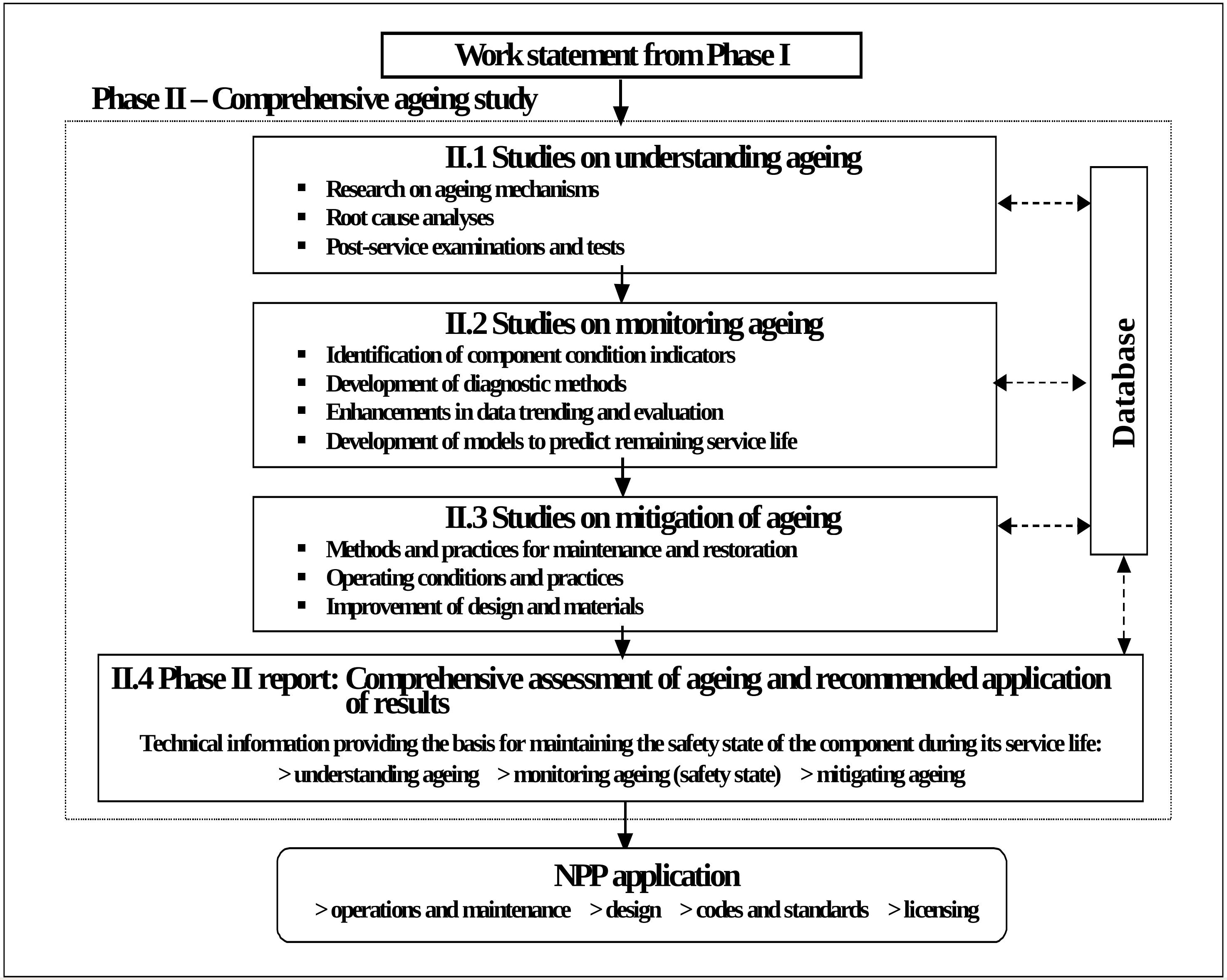
  Review effectiveness and consider changes of existing O&M practices for mitigating ageing degradation of the component

  - **Maintenance, refurbishment, and replacement**
  - **Operating conditions and practices affecting the rate of degradation**

Phase I report: Interim ageing assessment and recommendations for follow-up work

- Current understanding of component ageing:
  - **Significant ageing mechanisms and effects, defects characterization, safety significance of probable failure modes**
- Current monitoring of component ageing:
  - **Functional and condition indicators that should be monitored**
  - **Recommended methods and techniques**
- Current mitigation of component ageing:
  - **Recommended operating and maintenance practices**
- Recommendations for Phase II study:
  - **Any gaps in knowledge and technology**
  - **Work statement for Phase II addressing these gaps**

Phase II: Comprehensive ageing study



Studies on understanding ageing

- **Research on ageing mechanisms**
  - In-depth review of operating experience, in-situ and laboratory tests of naturally aged components, artificial ageing of components and their parts.
    - **Determine ageing mechanisms causing significant degradation of the component**
    - **Quantify effect of relevant factors (e.g. ambient environment, operating requirements and conditions) on the rate of degradation**

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Studies on understanding ageing (Cont'd)

Root cause analysis

- To determine the fundamental cause of component failure and any contributing factors
- Information from NPP records usually needs to be supplemented by interviews of plant personnel

Post-service examinations and tests

- Provide additional insight for understanding component ageing
- Most valuable, components that failed in service or had a long service life
- Evaluate component performance under normal and accident conditions, and its safety margins
- Compare findings with predictions of ageing

Studies on monitoring ageing

➢ Identification of condition indicators (CIs)

- An appropriate CI is a measurable parameter that undergoes a detectable change before component failure and can be used to predict future degradation and performance
- Objective: to identify candidates of appropriate CIs
- Examples: shift in nil-ductility transition temperature for RPV radiation embrittlement; leakage for containment isolation valve; vibration for rotating equipment

Studies on monitoring ageing (Cont'd)

➢ Development of diagnostic methods

Evaluation of component specific CI candidates for:

- **Measurability, selectivity (will not give false indications), sensitivity (will detect degradation in the incipient stage), accuracy, reliability, availability of acceptance/rejection criteria, practicability, and cost**
- **Laboratory tests using simulated component degradation/ defects**
- **Field tests to confirm laboratory results and practicality of application**

Both nuclear and non-nuclear technology should be evaluated.

Studies on monitoring ageing (Cont'd)

Data trending and evaluation

- Involves a comparison of measured data with previous measurements and with acceptance criteria
- Objective is to establish :
  - **which CIs should be monitored and trended**
  - **measurement frequency**
  - **how they should be evaluated to determine present and predict future physical condition and performance of the component**
  - **how they should be evaluated to determine the appropriate type and timing of maintenance**

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Studies on monitoring ageing (Cont'd)

➢ Remaining service life prediction

- From safety perspective, not necessary; it is sufficient to predict component degradation and performance capability till next inspection/ test
- From economic perspective, important for irreplaceable and very expensive SSCs, e.g. RPV
- Difficult and not well established as it involves understanding of multiple ageing mechanisms and effects, and correlation of rate of degradation with component CIs and functional indicators

Studies on mitigation of ageing

➢ Maintenance methods and practices

- Role of preventive maintenance is to preserve functional capability of a component by timely mitigation of ageing effects
- Study should identify or develop effective maintenance technologies and procedures for mitigating component degradation
- RCM methodology is used for optimizing maintenance programmes

Studies on mitigation of ageing (Cont'd)

➢ Operating conditions and practices

- Evaluate impact of possible changes on rate of component ageing degradation, including harmful side effects
- Examples of possible changes: reduce local stresses due to thermal and mechanical loads; reduce ambient temperature for materials susceptible to thermal ageing; modify system chemistry, modify testing and test frequency

➢ Design and materials

- Evaluate possible changes in component design or materials on the rate of its ageing degradation

Phase II report: Comprehensive ageing assessment and recommended application

- Comprehensive and coherent information on
  - Understanding ageing of the component
  - Monitoring its ageing
  - Mitigating its ageing
- Recommendations for application of Phase II results in NPP operation, maintenance, design, codes and standards
- Recommendations for data collection and record keeping to facilitate monitoring component ageing

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Data collection and record keeping for ageing management

Session 3.3

Resource document: Data Collection and Record Keeping for the Management of NPP Ageing, Safety Series No. 50-P-3 (1991)

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Report contents

- **Guidance on:**
  - data needs, and
  - data collection and record keeping system
- **Three categories of data:**
  - baseline information
  - operation history data
  - maintenance history data

  Component ID is used to cross-reference these data
- **Examples:**
  - data needs for reactor pressure vessel,
  - emergency diesel generator, electrical cables
  - record keeping systems

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General data needs for the management of ageing degradation

➢ **Baseline information:**

- define a component, its system and NPP
- describe initial, undegraded material condition and functional capability
- define design service conditions and operating limits

⇒ **Usually dispersed in numerous documents**

⇒ **Important to update baseline date when design is modified**

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General data needs for the management of ageing degradation (Cont’d)

Example of baseline information:

- Component ID, type and location
- Expected degradation mechanisms
- Design spec’s (e.g. service conditions, service life cycles)
- EQ spec’s (e.g. qualified life, normal and DBE service conditions, installation, operation and maintenance requirements)
- Manufacturer’s data (e.g. materials data, history docket for pressure retaining components)
- Commissioning data (e.g. on baseline vibrations and the inaugural inspection)
- Date of installation
- Information on design modifications

General data needs for the management of ageing degradation (Cont'd)

➢ Operating history data

- enable:

- comparison of design life usage with actual usage
- differentiation of age related failures, and identification of related ageing mechanisms
- tracking of failure rates of short lived components and correlation to service conditions
- assessment of operating and testing practices on component degradation
- assessment of maintenance effectiveness
- early identification of emerging ageing phenomena

⇒ Often available but difficult to retrieve

⇒ Compare NPP specific data with generic external data

General data needs for the management of ageing degradation (Cont'd)

- **Example of operating history data**

System service conditions
system ID; process conditions (p, T, flow), chemistry (pH, conductivity), noise (neutron, electrical, audio), system transient data (p-T and chemistry excursions)
Component service conditions
component ID; ambient environment (temperature, humidity, radiation), dates and profiles of component loading, cycling or startup, mode of operation (continuous, standby, intermittent), downtime periods
Availability testing data
component ID; test description, date of test, test result
Component failure data
component ID; date of failure, time or cycles to failure, method of failure discovery, failure mode, failure cause, failed parts, relevant system (unusual loading, power or signal) conditions, and environmental conditions

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General data needs for the management of ageing degradation (Cont'd)

- **Maintenance history data:**
  - Facilitate evaluation of maintenance effectiveness in preventing component failures, and adjustments of the timing and type of maintenance actions
  - Tracking the cost of maintenance at plant or system level can indicate increase in ageing degradation
  - Many requisite maintenance records are available, however, availability and quality of good condition monitoring data may be limitted

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General data needs for the management of ageing degradation (Cont'd)

➢ Example of maintenance history data

Component condition monitoring data
component ID; parameters to be monitored (vibration, temperature, chemistry), test and inspection results (including incipient failures and their dates, changes in condition monitoring
Component maintenance data
component ID; reason for maintenance action (incl. decision criteria), type of maintenance (corrective/preventive), date and duration of maintenance, work description (repair, refurbishment, replacement), changes in maintenance methods and intervals
Cost of maintenance
total cost of maintenance at NPP and possibly system level, total maintenance related radiation dose

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Component specific data needs

- can be derived from the above general data needs
- vary according to component type and category (concrete structure, pressure boundary, mechanical, electrical, I&C)
- screening questions for the general data needs:
  - **Is item necessary for evaluation of component's degradation and AM activities?**
  - **Can the item be measured with sufficient accuracy to permit the above evaluations?**

Component specific data needs
Example of Reactor Pressure Vessel

Baseline information
manufacturer, dimensions; expected degradation mechanisms (irrad. embrittlement, fatigue, SCC, wear); design specifications (neutron fluence for the design life, base metal and weld metal spec's, reference defects and p-T transients); original stress report; fabrication records (mechanical and chemical characteristics, pre-service inspection results); commissioning test data
Operating history data
transient data; neutron fluence; process conditions (p, T, flow rates within the vessel, time at temperature); primary water chemistry (oxygen, hydrogen, boron, conductivity)
Maintenance history data
ISI results; detected leaks; date, type and description of maintenance

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Component specific data needs Emergency diesel generator (EDG)

Baseline information
EDG identification (type, horsepower, manufacturer, starting system); no. of EDGs; performance requirements and generator rating; expected degradation mechanisms (wear, fatigue, corrosion, etc.)
Operating history data
process conditions (operating temp., oil pressure, fuel pressure); noise (vibration) data; ambient conditions; downtime (out of service); test type and frequency; test results; emergency use (time and duration); date and type (startup/running) of failure; failed parts; cause of failure
Maintenance history data
Condition indicators monitored (cranking speed, fuel/water/oil temperature and pressure, temperature of alternator winding and bearing); date and type of maintenance; cost of maintenance

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Component specific data needs
Electrical cables

Baseline information
cable ID; type (power/control/instrumentation, low/medium/high voltage, insulation/jacket material, manufacturer); cable location; quantity; expected degradation mechanisms; design spec's (voltage/current ratings); EQ (specifications, test conditions and results, qualified life); manufacturer data; commissioning data
Operating history data
cable ID; mode of op. (continuous/stand-by); ambient conditions (general and hot spots); failure data (date, mode of discovery and description); failed parts (jacket, insulation or conductor); environmental conditions relevant to failure; cause of failure
Maintenance history data
cable ID; visual inspection results; condition monitoring data; reason for maintenance action; description of work (repair/replacement)

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Data collection and record keeping system

System performance objectives

To provide:

- **comprehensive and accurate information on NPP components, including baseline, operation and maintenance histories**
- **secure storage of information**
- **timely and accurate retrieval of information**
- **tools for data analysis, graphical display and production of reports**
- **integrity of stored information over required time**

Data collection and record keeping system (Cont'd)

System design principles

- Data entry should be, to the extent possible, directly by operation and maintenance personnel, and should include appropriate quality control
- Relevant NPP databases should have common organization, format and central indexing
- Data should be stored digitally on stable media to facilitate data retrieval and manipulation
- Integrity of data should be carefully managed, with attention to the possibility of ageing degradation of records themselves

Summary of Module 3

Module 3 has presented:

- A safety oriented systematic screening process to identify a manageable number of NPP components whose ageing should be evaluated
- Methodology for AM studies of generic component types, and for ageing assessments of specific plant components
- Data needs for the management of ageing degradation
- System performance objectives and system design principles for an effective data collection and record keeping system