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# AGEING MANAGEMENT OF SAFETY NUCLEAR COMPONENTS

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## ABSTRACT

Ageing management of Nuclear Power Plants is an essential issue for utilities, in term of safety and in term of availability and corresponding economical consequences.

Practically all nuclear countries have developed a systematic program to deal with ageing of components on their plants.

This paper presents the different practices that are connected in general to the different safety requirements, and the different guidelines and examples developed by AIEA and that are generally used as reference documents by each country.

The paper presents a general overview of the programs and the major recommendations and conclusions.

**Keywords:** ageing, components, program, degradations.

## 1. INTRODUCTION

Managing ageing and remaining lifetime of an industrial facility is a concern that must be taken in account as soon as possible in daily activities. Bad practices may be detrimental in the short as well as the long term and the asset is of a considerable value.

EDF recognised very early the importance of that need for its nuclear facilities: 58 PWR units built on 20 sites are producing more than 75 % of electricity used in France. So that keeping these facilities in good operating conditions as long as possible is absolutely vital for the company.

And for nuclear power plants, "good operating conditions" undoubtedly means safety and cost-effectiveness.

In the same time, in 2001,USNRC has produced a specific document to be used for US utility license renewal: Generic Ageing Lesson Learns" (GALL report [7])

## 2. LIFETIME MANAGEMENT POLICY

In EDF, the lifetime management policy of the nuclear power plants is based on three principles:

- daily operation and maintenance activities, with an effective experience feedback organization taking advantage of the high level of standardization of the units,
- every ten years, a complete safety review of each group of similar plants, including ageing evaluation of Systems, Structures and Components (SSC)
- a Life Management Program, at corporate level, which permanently scrutinizes operation and maintenance activities to identify decisions which could impair plant lifetime and which surveys research and development programs related to ageing phenomenon understanding.

 

## 3. MAINTENANCE POLICY AND AGEING MANAGEMENT PROGRAM

### 3.1 General considerations

The maintenance policy and ageing management program are based on:

- strategic organization at corporate level, including comparison with international similar approaches,
- routine daily and exceptional maintenance,
- Exceptional maintenance
- 10-year ageing management program review and syntheses.

The "Exceptional Maintenance Program" is dedicated to periodic review of design, fabrication and experience feedback of the 30 to 40 most sensitive components. This program has to identify possible future problems, to estimate potential consequences and to propose appropriate measures to be taken.

Of course, consequences of the "anticipation / no anticipation" choice must be integrated on the whole plant lifetime.

### 3.2 Ageing management program (AMP) review

The major objectives of this 10-year basic activity is to justify that all the safety important systems, structures and components (SSC), concerned by an ageing mechanism, remain in the design and safety criteria, including all feedbacks from the field.

This ageing occurs along normal operation, including periodic tests and routine maintenance activities (like opening and closing of components).

This ageing of SSC's is considered under control through different actions:

- prediction and detection, early in the SCC life, of degradations that can affect design rules (integrity of barriers) or safety function of the plant (final safety analysis report: FSAR),
- definition of mitigation and corrective actions (including repair, replacement) to assure the safety level of the plant and the economic competitiveness of the final decision on anticipation process bases.

This ageing management program review is formed of 3 steps [9]:

- selection of structures and components,
- specific report to continue operation of the more sensitive components and structures
- synthesis report.

All these reports have to be prepared in accordance with the French regulation, as the decree for surveillance of primary and secondary system [1] and the different French Codes & Standards, as RCC-M [2] and RSE-M [3].

## 4. FRENCH PROCEDURE FOR AMP REVIEW

### 4.1 Structure and component selection

The selection is based on the FSAR that defines rules for safety importance of components and structures:

- mechanical components: class 1-2-3
- electrical components: class 1E
- civil engineering structures: connected to safety

Some other aspects are considered as seismic classification and qualification requirements; but this paper is focused on passive mechanical components.

Around 15000 components are concerned by plant. The selection is based on the different ageing degradation mechanism that can affect a part of each components and structures.

In order to do that systematically and with a minimum of references that support the decisions, we proposed a specific grid [9] with one line per components, structures or part of them for each potential degradation mechanism. In the same time different other information's are collected through the columns:

- is the degradation mechanism potential or encountered in French or International similar plant?
- did we encounter difficulties that can have affected a safety function?
- is the degradation mechanism analyzed in the design report? If yes, what is the expected life in this report?
- is the present maintenance program adapted, easy to adapt or un-adapted for this degradation mechanism?
- is the repair easy or difficult for this degradation mechanism and this location?
- is the replacement of the component easy or difficult? Do we have any risk of obsolescence of the components (no vendor available or no manufacturer of this type of components)?

Around that grid a specific procedure document has been issued and complementary information are attached:

- list of degradation mechanisms (more than 30 different mechanisms)
- list of consequences of degradation mechanism, like crack, thinning, lost of mechanical properties…

 

After the fill up of the grid each component or group of components (with similar function or similar degradation or similar design…) is affected in 3 categories: 0-1-2:

- 0: no complementary studies
- 1: complementary analysis to rank it as 0 or 2
- 2: prepare a specific justification report to confirm the continuation of operation

The basis of this categorization is presented in the following table 1.

A specific data sheet is attached to each line of the grid in order to collect all the references used to fill up the grid.

### 4.2 Report to justify continuation of operation

For the category 2 components or structures, a report has to be produced to justify on what basis continuation of operation can be done.

This report has to collect and identify references and present it as follow:

- introduction
- description: design, materials, fabrication process, water chemistry
- design basis: regulation, codes & standards, specification and guidelines
- operating experience and ageing mechanism
- assessment methods of corresponding ageing mechanisms
- inspection, monitoring, leak detection
- mitigation, repair, replacement
- synthesis of ageing management program recommendations

### 4.3 Synthesis report

This synthesis report has to collect the major information of the 2 previous steps: selection and report to justify continuation of operation in order to compare with existing practices for the component or the structure.

It has to propose a set of recommendation based on the different information collected and the economic aspect of the decisions.

*Table 1: Selection of components and structures*

| | Potential ageing mechanism | | |
|---|---|---|---|
| maintenance | adapted | easy to adapt | difficult to adapt |
| Repair **and** Replacement difficult | **0** | **1** | **2** |
| Repair **or** Replacement easy | **0** | **1** | **1** |
| | Encountered ageing mechanism | | |
| maintenance | adapted | easy to adapt | difficult to adapt |
| Repair **and** Replacement difficult | **2** | **2** | **2** |
| Repair **or** Replacement easy | **0** | **1** | **2** |

## 5. STATUS OF FRENCH APPLICATION

The French oldest plant is in operation since 1977 and EDF is preparing the 3rd 10-year shutdown for this plant and a group of 28 similar plants (3-loop PWR).

The first application of the procedure lead to around 31 components in category 2, 260 in category 0 and 115 in category 1. We are planning the corresponding 31 "Report to justify continuation of operation" for mid of 2005.

Finally for a large list of components and structures the existing AMPs are adequate. The list of category 2 location/damage can be attributed to 10 components and structures where existing AMPs have to be reviewed for, if necessary, improved them on some aspects:

- reactor pressure vessel
- reactor pressure vessel internals
- steam generator
- pressurizer
- main coolant line of primary system
- auxiliary lines connected to primary system
- reactor coolant pump
- containment
- I&C components
- cables

## 6. COMPARISON WITH INTERNATIONAL APPROACHES

Different comparisons are done on the basis of public documents.

The major comparisons are done with:

- AIEA guidelines and TEC-DOC reports on ageing [4, 5, 6]
- the Generic Ageing Lessons Learned (GALL) report from NRC [7]
- different reports from OECD-NEA-IAGE group [8]

### 6.1 SUMMARY OF GALL REPORT

The USNRC GALL report contains an evaluation of a large number of structures and components. The evaluation results documented in the GALL report indicate that many of the generic existing programs are adequate to manage ageing effects for particular structures or components for license renewal without change. The GALL report also contains recommendations on specific areas for which generic existing programs should be augmented for license renewal and documents the technical basis for each such determination.

In the GALL report- Volume 1, Tables 1 through 6 are summaries of the ageing management review. Descriptions of the specific item numbers used in the GALL report, Volume 2, Chapters II through VIII, are given in the Appendix of Volume 1. A locator for the plant systems evaluated in Volume 2 is also provided in the Appendix of Volume 1. The specific item number and associated ageing effect serve as a pointer to the technical evaluation for the specific structure and component addressed in Volume 2 (Tabulation of Results).

The GALL report provides a technical basis for crediting existing plant programs and recommending areas for program augmentation and further evaluation. The incorporation of the GALL report information into the SRP-LR, as directed by the Commission, should improve the efficiency of the license renewal process and better focus staff resources.

### 6.2 COMPARISON OF GALL AND EDF RESULTS

*Objectives*

For the French side, it's a complementary action that is planned around the 10-year shutdown including in the periodic safety review. During this 3rd 10-year shutdown of these 3-loop plants we have to guarantee that all the ageing mechanism of safety components is under control for the next 10 years and to assure no important acceleration of the ageing after the next 10 years (no license process in France).

It's slightly different in USA where NRC attributes a 40 year-license to the utilities. This GALL report will be used has a reference technical document to renew the license from 40 to 60 years (with no question in this study on the 40-year period which is treated through an other existing procedure).

*Scope*

The SCCs concerned is more limited in the French study than in the GALL report. Mainly on the concern of balance of plant SSCs, those are largely covered by the GALL report, and are not considered as safety important SCCs in French approach. Table 2 presents the 2 lists of SCCs considered; they are roughly similar with some minor differences, like cranes...

In order to compare in detail, Table 3 presents all the components and local areas covered in the 2 approaches for class 1 mechanical components. Similar comparisons can be done for other SSCs.

For class 1 components the different components and local areas concerned are again similar with some minor differences like Main Coolant Pump shaft, wheel, thermal barrier and Joins, or Steam Generator internal tube bundle skirt, or pressurizer heater or Reactor Pressure Vessel keys support.

*Comparison of degradation mechanism*

Again the major list is similar for metallic components: irradiation, fatigue, boric acid corrosion, primary water stress corrosion cracking, secondary side stress corrosion cracking, thermal ageing, stress relaxation, wear, swelling, corrosion-erosion, vibration fatigue, general corrosion, pitting, oxidation.

Specific treatment of some degradation mechanisms are done in the French study, like:

- thermal ageing of low alloy and carbon steels welds and cladding heat affected zones,
- tribo-corrosion of control rod mechanism,
- environmental fatigue of carbon steel under high oxygen content water,
- ratcheting, of some components
- fouling of heat exchangers,
- creep relaxation of RPV internal bolts…

*Comparison of Code Ageing Management requirements and Specific Ageing Management Program*

The ASME Code section XI and the French RSE-M are different in term of In-Service Inspection frequencies and requested performances. The French ISI program is mainly "damage oriented" and just with some minor complementary sampling. The ASME Code is the contrary, basically sampling plus complementary inspection programs (augmented ISI) like stratified or dead leg situation in piping systems.

Some examples of differences in Ageing Management Program are presented below. The different reasons for those situations are: regulatory requirements, code requirements and R&D backgrounds on degradation mechanisms.

A specific extensive ISI program is implemented in France on all Alloys 600 locations (base metal and welds) since many years; the corresponding program is just starting in USA with vessel penetration as a priority.

The French ISI program for RPV is mainly turn toward small underclad cracks on all the irradiated surface of the RPV beltlines; it remains focused on embedded cracks in the weld area in USA.

An extensive program is done to understand thermal ageing of cast duplex steel components (elbow, inclined nozzle, valves); a minimum program is done in USA with elbow over 20% ferrite contents only.

For low cycle fatigue, USNRC ask to take in consideration the environmental effects for all materials and environments. In France, the different tests done on laboratory loops with stainless steel components do not required any negative environmental corrective factors; for secondary side carbon steel component, only few of them are concerned (chemistry threshold) and for only some deviation in the chemistry control of the secondary side water.

High cycle thermal fatigue of tee junctions is not cover in USA; large program in France confirms that some nozzles are sensitive to that type of degradation mechanism (like charging line and RHR nozzles, MCP shaft…).

Thermal ageing of low alloy and carbon steel welds and heat affected zone (weld and cladding) over 300°C can be sensitive to this degradation mechanism in French study, not in USNRC GALL report.

## 7. CONCLUSIONS

A detailed, systematic and documented procedure is now available in France. The corresponding results are expected for 3-loop plants before mid 2005 in order to confirm, or update if necessary, the actual practices (routine plus exceptional maintenance).

The key issue for the success of this type of review is a perfect understanding and quantification of the different ageing mechanisms that has to be improved at the national and international level.

In the same period of time, NRC has issued the GALL report in order to support the license renewal process of US plants. A general comparison of major results confirms: a similar scope between these 2 studies, similar list of components and similar list of locations in each component.

The major differences are:

- the slightly different objectives: license renewal from 40 to 60 years versus 10-year periodic safety review for the next 10 years of operation,
- different understanding of some degradation mechanisms, like thermal ageing of different materials (cast duplex stainless steel and low alloy steel), high cycle fatigue, environmental fatigue issue

Detailed AMP that are derived from National regulatory requirements, national code requirements and different national specific programs, can be slightly different to assure safety and economical maintenance costs. We learned a lot from the different international AMP and we proposed a synthesis through the French ageing management program. Consequently it can be transposed for the technical aspect to a lot of PWR or VVER plants.

This paper is focused on class 1 mechanical components and will be extended to other SSCs in the future, and confirm a good consistent approach between Design and Fabrication in one hand and operation and maintenance in the other hand..

## REFERENCES


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[3] RSE-M Code, "Rules for In-service Inspection of Nuclear Power Plant Components", 1997 Edition + 1998 and 2000 addenda, AFCEN, Paris.

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| - List of GALL report SSCs | - List of EDF procedure SSCs |
|---|---|
| **1. Containment Structures** | **1. Containment Structures** |
| Concrete Containments (Reinforced and Prestressed)<br>Steel Containments<br>Common Components | Concrete Containments (Reinforced and Prestressed)<br>Penetrations: piping, electrical, material hatch and personnel access |
| **2. Reactor Coolant System** | **2. Reactor Coolant System** |
| Reactor Vessel<br>Reactor Vessel Internals<br>Reactor Coolant System and Connected Lines<br>Steam Generator | - Reactor Vessel/ Reactor Vessel Internal<br>- Reactor Coolant System and Connected Lines<br>- Steam Generator/ Pressurizer/ Reactor coolant pump<br>- Valves |
| **3. Engineered Safety Features** | **3. Class 2 and 3 Mechanical components** |
| Containment Spray System<br>Containment Isolation Components<br>Emergency Core Cooling System<br>Carbon Steel Components | - Piping/ Vessels/ Heat exchangers/ Valves<br>- Pumps/ Turbo-pumps |
| **4. Auxiliary Systems** | **4. Auxiliary System Components** |
| New/Spent Fuel Storage/ Spent Fuel Pool<br>Refueling Handling Systems<br>Open-Cycle Cooling Water System<br>Ultimate Heat Sink<br>Compressed Air System<br>Chemical and Volume Control System<br>Control Room Area Ventilation System<br>Heating and Ventilation Systems<br>Fire Protection<br>Diesel Fuel Oil System/ Emergency Diesel Generator System | - Fire protection system<br>- Ventilation systems<br>- Water filtration systems |
| **5. Steam and Power Conversion System** | **5. Other civil engineering structures** |
| Steam Turbine System<br>Main Steam System<br>Extraction Steam System<br>Feedwater System<br>Condensate System<br>Steam Generator Blowdown System<br>Auxiliary Feedwater (AFW) System<br>Carbon Steel Components | - Nuclear Structures<br>- Site buildings and structures<br>- Non-metallic Piping<br>- Cooling tower<br>- Pools<br>- Fire protection devices |
| **6. Structures and Components Supports** | **6. Instrumentation and Control components** |
| Class 1 Structures<br>Group 3 Structures (Auxiliary Buildings)<br>Group 4 Structures (Containment Internal Structures)<br>Group 5 Structures (Fuel Storage Facility)<br>Group 6 Structures (Water-Control)<br>Group 7 Structures (Concrete)<br>Group 8 Structures (Steel Tanks)<br>Component Supports<br>Anchorage of Racks, Panels, Cabinets<br>Supports for Platforms, Pipe Whip Restraints, Jet Impingement Shields/ Masonry Walls | - Control room/ Safety panel<br>- Hydrogen/ Flow rate/ Neutron/ Temperature/ Pressure instrumentation<br>- Detectors/ Captors/ Probes<br>- Relays<br>- Position detectors |

**Table 2 : Comparison of the GALL report and EDF procedure list of SSCs considered**

| 7. **Electrical Components** | 7. **Electrical components** |
|---|---|
| Electrical Cables and Connections Not Subject to 10 CFR 50.49 Environmental Qualification Requirements<br>Equipment Subject to 10 CFR 50.49 Environmental Qualification Requirements | - Motors/ Compressors<br>- Cables and Cable Trays<br>- Diesel/ Transformers/ Convertissers<br>- Electrical Cabinets<br>- Batteries |
| | 8. **Handling devices: cranes…** |

**Table 2 (continued) : Comparison of the GALL report and EDF procedure list of SSCs considered**

| - **List of GALL report class 1 components** | - **List of EDF procedure class 1 components** |
|---|---|
| 1. **Reactor Vessel** | 1. **Reactor Vessel** |
| **Closure Head:** Dome, Head Flange, Stud Assembly, Vessel Flange Leak Detection Line<br>**Vessel Flange**<br>**Control Rod Drive Head Penetration:** Nozzle, Pressure Housing, Flange Bolting<br>**Nozzles and safe ends:** Inlet, Outlet<br>**Shell:** Upper Shell, Intermediate and Lower Shell<br>**Bottom Head**<br>Core Support Pads/Core Guide Lugs/Instrument Tubes<br>Pressure Vessel Support<br>Skirt/ Cantilever/ Column Support<br>Neutron Shield Tank | **Closure Head:** Dome, Head Flange, Stud Assembly<br>**Vessel Flange**<br>**Control Rod Drive Head Penetration:** Nozzle<br>**Nozzles and safe ends:** Inlet, Outlet<br>**Shell:** Upper Shell, Intermediate and Lower Shell<br>**Bottom Head**<br>- **Pressure Vessel Support**<br>- **Canopy Joins**<br>- **Alloy 600 repair location**<br>- |
| 2. **Reactor Vessel Internals** | 2. **Reactor Vessel Internals** |
| **Upper Internals Assembly:**<br>Upper Support Plate/ Column/ Bolts<br>Upper Core Plate/ Alignment pins<br>Fuel Alignment Pins<br>Hold-Down Spring<br>**RCCA Guide Tube Assemblies:**<br>RCCA Guide Tubes/ Bolts/ Support pins<br>**Core Barrel:**<br>Core Barrel/ Flange/ Outlet nozzles<br>Thermal Shield<br>**Baffle/Former Assembly:**<br>Baffle and Former Plates/ Bolts<br>**Lower Internal Assembly:**<br>Lower Core Plate<br>Fuel Alignment Pins<br>Lower Support Forging or Casting/ Plate columns<br>Lower Support Plate Column Bolts<br>Radial Support Keys and Clevis Inserts/ Bolts<br>**Instrumentation Support Structures:**<br>Flux Thimbles/ Guide Tubes | **Upper Internals Assembly:**<br>Upper Support Plate/ Column/ Bolts<br>Upper Core Plate/ Alignment pins<br>- Fuel Alignment Pins<br>- **RCCA Guide Tube Assemblies**<br>**Core Barrel:**<br>Core Barrel<br>Thermal Shield<br>**Baffle/Former Assembly:**<br>Baffle and Former Plates/ Bolts<br>**Lower Internal Assembly:**<br>Lower Core Plate<br>Fuel Alignment Pins<br>Lower Support Forging or Casting/ Plate columns<br>Lower Support Plate Column Bolts<br>Radial Support Keys and Clevis Inserts/ Bolts<br>**Instrumentation Support Structures:**<br>- Flux Thimbles/ Guide Tubes |

**Table 3: Comparison of the GALL report and EDF procedure list of class 1 components**

 

| 3. Reactor Coolant System and Connected Lines | 3. Reactor Coolant System and Connected Lines |
|---|---|
| **Reactor Coolant System Piping and Cold Leg**: Hot Leg, Surge Line, Spray Line, Small-Bore RCS Piping, Fittings, and Branch Connections less than NPS 4<br>**Connected Systems Piping and Fittings**: Residual Heat Removal or Low Pressure Injection System, Core Flood System, High Pressure Injection System, Chemical and Volume Control System, Sampling System, Drains and Instrument Lines, Nozzles and Safe Ends, Small-Bore Piping, Fittings, and Branch **Connections less than NPS 4 in Connected Systems**<br>**Reactor Coolant Pump**: Casing, Cover, Closure Bolting<br>**Pressurizer**: Shell/Heads, Spray Line Nozzle, Surge Line Nozzle, Spray Head, Thermal Sleeves, Instrument Penetrations, Safe Ends, Manway and Flanges, Manway and Flange Bolting, Heater Sheaths and Sleeves, Support Keys, Skirt, and Shear Lugs, Integral Support<br>**Pressurizer Relief Tank**: Tank Shell and Heads, Flanges and Nozzles | - **Reactor Coolant System Piping and Cold Leg**: Hot Leg, Surge Line, Spray Line,<br>- **Connected Systems Piping and Fittings**: Residual Heat Removal, Low Pressure Injection System, High Pressure Injection, Chemical and Volume Control System, Sampling System, Drains and Instrument Lines<br>- **Small-Bore Piping**<br>- **Valves**: pressurizer SEBIM valve and other class 1 valves<br>**Reactor Coolant Pump**: Casing, Cover, Closure Bolting, MCP wheel, thermal barrier, n°1 and 2 joins, shaft, support<br>- **Pressurizer**: Shell/Heads, Spray Line Nozzle, Surge Line Nozzle, Spray Head, Thermal Sleeves, Instrument Penetrations, Safe Ends, Manway and Flanges, Manway and Flange Bolting, Heaters, Heater Sleeves, Support Keys, Skirt |
| 4. **Steam Generator** | 4. **Steam Generator** |
| **Pressure Boundary and Structural:**<br>Top/ Lower Head<br>Upper and Lower Shell/ Transition Cone<br>Steam Nozzle and Safe End<br>Feedwater Nozzle/ Safe End<br>Feedwater Impingement Plate and Support<br>Primary/ Secondary Manway and Handhole<br>Primary Nozzles and Safe Ends<br>Instrument Nozzles<br>**Tube Bundle:**<br>Tubes and Sleeves/ Tube Plugs/ Tube Support Plates<br>**Upper Assembly and Separators:**<br>Feedwater Inlet Ring and Support | **Pressure Boundary and Structural:**<br>Top/ Lower Head<br>Upper and Lower Shell/ Transition Cone<br>Steam/ Feedwater Nozzles<br>Primary/ Secondary Manway and Handhole<br>Primary Nozzles and Safe Ends<br>**Tube Bundle:**<br>Tubes and Sleeves/ Tube Plugs/ Tube Support Plates<br>Tubes and anti-vibration bars<br>**Upper Assembly and Separators:**<br>- Feedwater Ring and Support Internal tube bundle skirt and supports |

**Table 3 (continued) : Comparison of the GALL report and EDF procedure list of class 1 components**