ABSTRACT

Ageing management of Nuclear Power Plants is an essential issue for utilities, in term of safety and availability and corresponding economical consequences. Major nuclear countries have developed a systematic program to deal with ageing of components on their plants and some of them are working in the same time for long term operation consequences. This paper presents the ageing management program developed by EDF and that are compared with some other approaches in other countries (IAEA guidelines and GALL report).

The paper presents an example of application to large diameter safety class piping. Different degradation mechanisms are considered like fatigue, corrosion or thermal aging…. Maintenance and surveillance actions are discussed in the paper.

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. Collection of relevant plant data is an important contributor in order to largely reduce uncertainties.

EDF recognized 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 (figure 1).

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

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 [1]), a revised version has been issued recently, EDF has done a comparison of methodology and results for French and USA PWRs.
LIFETIME MANAGEMENT POLICY

In EDF, the lifetime management policy of the nuclear power plants is based on for principles:
- **daily operation and maintenance** activities, with an effective experience feedback organization taking advantage of the high level of standardization of the units,
- "**Exceptional Maintenance Program**" in charge 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.
- every ten years, the periodic safety review of each group of similar plants, includes ageing evaluation of Systems, Structures and Components (SSC)

This periodic safety review includes:
- up-dating of the initial stress report to check all the data that are different in operation than in design analysis
- up-dating of all deviations discovered in fabrication and in operation (thinning, cracks…)
- ageing management program review
- maintenance and surveillance program review
- 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 and economical aspects.

**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 [2] is formed of 3 steps (figure 3).
- **selection** of structures and components and 1st level analysis,
- **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 example, for the pressure boundary equipments : the decree for surveillance of primary and secondary
system [3] and the different French Codes & Standards, as RCC-M [4] and RSE-M [5]. Any changes in these requirements has to be analyzed regularly.

A large effort has been done on justification, tracability and references used to prepare all these reports.

FRENCH PROCEDURE FOR AMP REVIEW

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

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 (figure 4) 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?
- 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)?

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 2 categories: 0-2 (figure 2):
- 0: no complementary actions needed
- 2: prepare a specific justification report to confirm the continuation of operation

A specific data sheet (figure 5) is attached to each line of the grid in order to collect all the references used to fill up the grid.

Report to justify continuation of operation

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

This report has to collect and identify references and present it as follow:
- Part 1 : equipment/ structure description/ construction/ experience description, functions, safety and regulation requirements, rules and synthesis of design and fabrication reports, operating conditions, operating experience
- Part 2: degradation mechanisms, synthesis of scientific knowledge of each mechanism, damage rate and fitness for service analysis, mitigation, surveillance and ISI, repair process
- Part 3: Industry capacity, repair, replacement, industry network, competency and tools availability.
- Obsolescence has been study under a specific procedure.
- Part 4: Maintenance or surveillance program review, complementary analysis or R&D program, if necessary.

**Synthesis**

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.

**STATUS OF FRENCH APPLICATION**

The procedure has been applied in 2003-2004. The corresponding reports are now under evaluation by French Safety Authority.

The French oldest plant is in operation since 1977 and EDF, all the conclusion have to be analyzed before the 3rd 10-year shutdown for this plant, in 2008-2009. It’s the 1st plant of a group of 28 similar plants (3-loop PWR).

The application of the procedure lead to around 50 locations in category 2 and 350 in category 0.

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 12 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
- electrical containment penetrations
- civil engineering structures
- I&C components
- cables

**COMPARISON WITH INTERNATIONAL APPROACHES**

The EDF approaches has been compared with AIEA guidelines [6,7,8], GALL report and similar programs in Japan, Switzerland or other countries.

For example for the GALL report [1]:

Claude FAIDY, EDF (France)
Overview of EDF ageing management program of safety class components
- the approaches are similar but some degradation understandings are different
- different objectives: LR / PSR
- larger scope in GALL report (PWR and BWR, safety and non-safety SSCs)
- similar, but not identical list of components, locations, degradation mechanisms for PWRs

For mechanical components: different regulation, C&S, specific AMP.

Different understanding of some degradation mechanisms, as:
- limited "potential" degradation based on laboratory knowledge
- more based on USA than International field experience; more international cross check in EDF approach
- more environment effect in fatigue in GALL
- less thermal ageing in GALL
- no high cycle thermal fatigue in GALL

APPLICATION TO MAIN COOLANT LINES AND CONNECTED LINES

General description of French MCLs

The French plants have 3 or 4 loops with one reactor pump (RCP) in each loop. The main connected lines are: a surge line, safety injection lines, charging line and residual heat removal lines.

The designs for French PWR's are similar to Westinghouse PWR design (figure 6).

Inside diameter of these lines are around 736mm and corresponding thickness around 64mm to 72mm.

The design pressure is 17.23 MPa and design temperature around 343°C, for a lower temperature of 7°C during safety injection.

The different materials encountered in French plants are: 316L/304L, CF8M/CF8 (for elbows or some straight pipes)

Specific requirements are imposed to the water chemistry in accordance with EPRI guidelines.

Design basis: regulations and codes

The MCL and connected line piping are subjected to French regulation and French codes.

French have developed their own codes (RCC-M/RSE-M [4,5]) in order to fulfill specific regulatory requirements and to fit with their own industrial organization.

The different damages considered in these Codes are mainly:
- plastic deformation
- collapse load
- buckling
- fatigue on the basis of a detailed design transient list
- rupture and, partially corrosion

For different damages the safety factors are clearly expressed in the Code (plastic instability or buckling), for some others they are not (rupture or plastic shakedown). Some other potential damages are not necessary strictly covered by the existing Codes (corrosion or vibration fatigue).
Different levels of criteria are proposed by the Code in accordance with the frequency of the transient. For level D criteria a combination of MCL and connected line rupture with seismic event are generally considered.

The design lifetime is generally of 40 years of operation. Different pilot studies are ongoing to define how this initial design life could be extended to 50 or 60 years.

**Operating experience**

For MCL:
- no new cracks and no crack growth of fabrication defects have been discovered on MCL welds after more than 20 years of operation
- few cast fabrication defects have been discovered on duplex steel elbows (227 inspected elbows, 34 with defects, maximum length 36mm)
- some defects on stainless steel dissimilar metal welds have been encountered in operation

For connected lines:
- thermal fatigue in piping connected to cold leak at valve level:
  - leaks on safety injection lines, around 6" diameter
- high cycle thermal fatigue in piping
  - vortex in connected line without flow rate
- corrosion in piping
  - different cracks or thinning attributed to different corrosion mechanism (polluted water by resins, multiple repairs and boric acid water, stress corrosion cracking in weld areas…)
- field experience on nozzles
  - Crystal River, Oconee, Fessenheim, Biblis, Neckar
  - generally connected to thermal sleeve vibration

Outside of this experience on class 1 piping we have to consider the different cases of high cycle thermal fatigue in mixing tees encountered in Sweden, France and Japan; some of them are encountered on thinner class 2 (or less) piping systems.

**Ageing mechanism**

Six ageing mechanisms have been analyzed for MCL piping: thermal fatigue, vibration fatigue, thermal ageing, primary water stress corrosion (PWSCC) cracking, different corrosion mechanisms.

Some of these damages have been encountered:
- low cycle thermal fatigue, mainly in connected lines and nozzles
- high cycle thermal fatigue on dead leg piping or mixing tees (figure 9)
- vibration fatigue, mainly on small connected lines and thermal sleeves
- thermal ageing of cast duplex stainless steel elbows and nozzles (figure 7)
- PWSCC of dissimilar metal welds (not in France)
- boric acid corrosion, mainly on outer surface and connected to a leak
- corrosion on some but-welds or DMW (figure 8)

Some are not encountered in class 1 piping systems, or not completely sure, just possible through analysis or laboratory tests:
- high cycle fatigue for high DT in mixing tees or nozzles (as charging line nozzle)
- thermal ageing of welds and dissimilar metal welds

**Assessment methods**

All these degradation mechanisms are not covered by design code rules, except low cycle fatigue. All the others are considered to be not active by material choices, fabrication qualification and installation and pre-test analyses. Nevertheless, all the design code rules considered mainly initial material properties and not end of "real" life values.

Concerning the capability of managing these degradation mechanisms, general assessment methods are available (low cycle fatigue, thermal ageing of cast stainless steels) or under development through R&D programs (flaw tolerance of DMW [9] high cycle thermal fatigue [10]) in order to define the threshold of activation of this mechanism, its kinetic to predict potential degradation rate and fitness for service criteria.

Operation specification and surveillance programs are used to assure high safety level of these corresponding lines: fatigue monitoring systems, leak detection systems, in-service inspection of more sensitive areas (with some limitation of performance for some materials) using different qualified techniques up to replacement of piping or nozzle for more detailed expertises, reduction of loads when it's possible... In some cases, repair (welds, surface degradation) and replacement techniques are available and could be implemented (class 1 nozzles, thermal sleeves).

**Conclusions for MCL and connected lines**

The MCL and connected line piping systems of existing PWRs have generally a very high quality standard for design, fabrication and operation rules. The corresponding field experience confirms very limited degradations encountered in these systems.

Nevertheless, some degradations appears with long operation time, like thermal ageing of cast components or thermal fatigue in mixing tees. Recently (SCC of DMW in VC SUMMER and RINGHALS, FAC in MIHAMA), some have no consequences encountered (as loss of toughness by thermal ageing of welds), some are potential and not encountered for the moment (but no ISI can justify absence of early degradation due to the thickness of these piping systems) like high DT in mixing tees [9].

The MCL and connected line reliability remains very high, but an important effort has to be maintain to understand, case by case, encountered and potential degradation mechanisms.

All these studies on piping are associated to 2 important aspects for piping systems : leak before break and risk informed approaches. The corresponding studies have to be reviewed to assure initial approaches and margins.

It's an essential contribution to assure long term high safety level of PWR plants and cost effectiveness through anticipated actions at all the necessary levels (R&D, ISI, repair, replacement including spare parts management).
CONCLUSION

EDF plant operation include a large Ageing Management Program based on 3 different steps:
- daily routine maintenance
- exceptional maintenance
- ageing management program review.

The French regulatory practice is based on periodic safety review every 10 years without maximum life value. Presently EDF has submit a complete set of reports to justify an acceptable ageing management program for 40 year of operation of 3-loop PWR plants. Some studies are now on-going to study longer life.

The French regulation has specific requirements on:
- periodic re-assessment of the initial stress report, including re-evaluation of fabrication and service-induced defects, maximum every 10 years
- ISI performance demonstration, with larger scope and more stringent criteria than in many other countries [11]
- periodic re-qualification including ISI and hydro-proof test (1.43 time or more the design pressure at the end of fabrication and 1.2 time design pressure in operation)

The specificities of the program are:
- an anticipation process, essential in front of the number of plants and corresponding contribution to electricity production in France
- a review of national and international field experience
- a living knowledge data bank on degradation mechanism (encountered and potential)
- a large R&D program in different directions (degradation mechanism, fitness for service criteria, in-service inspection techniques, repair process and consequences on the residual life of the components…)

Different on-going developments will be important contributors for future decision process, like:
- leak before break
- probabilistic approaches
- partial safety factors
- risk-informed approaches

Managing ageing and remaining lifetime of NPPs is an important concern for EDF that has be taken in account early 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. Collection of relevant plant data is an important contributor in order to largely reduce uncertainties.

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


9. C. Faidy, "Structural Integrity of dissimilar welds : ADIMEW project overview", ASME-Pressure Vessel and Piping conference, July 2004, San Diego, USA

10. C. Faidy, "Thermal Fatigue in Nuclear Power Plants : French experience and on-going program", 3rd International Conference on Fatigue of Reactor Components, EPRI - US NRC - OECD NEA, Seville, Spain, October 3-6, 2004

Figure 1: EDF plant first operation year

Figure 2: Definition of status of each locations

<table>
<thead>
<tr>
<th>Degradation mechanism</th>
<th>Encountered</th>
<th>Predicted</th>
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<tbody>
<tr>
<td>Building maintenance program</td>
<td>OK</td>
<td>Difficult to be OK</td>
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<tr>
<td>Repair and replacement difficult</td>
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<td>2</td>
</tr>
<tr>
<td>Repair replacement not difficult</td>
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<td>2</td>
</tr>
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0: nothing, without any new information
2: prepare a detailed ageing analysis report

Figure 3: General AMP review through 3 major steps

Claude FAIDY, EDF (France)
Overview of EDF ageing management program of safety class components
<table>
<thead>
<tr>
<th>Component/Structure</th>
<th>Element Zone</th>
<th>Potential mechanism</th>
<th>Encountered mechanism</th>
<th>Safety function affected</th>
<th>Design life in years</th>
<th>Routine maintenance considered</th>
<th>Repair</th>
<th>Replacement</th>
<th>Degradation Exceeded</th>
<th>Status</th>
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<td>N</td>
<td>40</td>
<td>AE</td>
<td>M</td>
<td>M</td>
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<td>Outlet nd Fat</td>
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<td>AE</td>
<td>M</td>
<td>M</td>
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<td>001.02.2A</td>
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**Figure 4: Grid example**

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<tr>
<th>Component/Structure</th>
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</tbody>
</table>

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<th>Points of the grid</th>
<th>Response</th>
<th>Justification/Commentaires</th>
<th>References</th>
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<td>Damage (potential)</td>
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<tr>
<td>Damage (method)</td>
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<td>Summary</td>
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**Figure 5: Ageing datasheet example**
Figure 6: MCL description

Figure 7: Inclined safety injection nozzle

Figure 8: French Dissimilar Metal Welds
Figure 9: Different thermal fatigue cases