AGEING MANAGEMENT PROGRAM
STATUS OF FRENCH APPLICATION AND R&D SUPPORT

Claude Faidy

EDF-SEPTEN Villeurbanne, France
e-mail: claude.faidy@edf.fr

ABSTRACT

During the past 10 years many works have been done on Ageing Management Program of Safety classed components in different countries.

The paper will describe all the different aspects concerning these programs, and in particular the EDF step by step procedure and the major results.

To-day, EDF is preparing the 3rd ten-year shutdown of all these 3-loop plants (34 plants). During the associated Safety Review, a specific task is devoted to ageing effects and control of all the safety concerned components. A large list of components has been reviewed: mechanical, civil engineering, instrumentation and control, cables, non metallic components. Few non safety but important in term of availability components are considered, like turbine or some balance of plant components. A general review of results and difficulties for 40 and 60 years are presented in the paper.

The second part is devoted to a short review of R&D associated program.

The major conclusions are clearly supporting the needs of international procedure harmonization on all the different topics.

INTRODUCTION

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

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

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

EDF recognized since the beginning of plant operation the importance of that need for its nuclear facilities: 58 PWR (Pressurized Water Reactor) units built on 20 sites are producing more than 75 % of electricity used in France (Table 1). Keeping these facilities in good operating conditions as long as possible is economically important for EDF, before a progressive replacement of these existing plants by new reactors.

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

In parallel, in 2001, USNRC (United State Nuclear Regulatory Commission) produced a specific document to be used for US utility license renewal: Generic Ageing Lesson Learn" (GALL report) [2]. Different other countries are on the way to develop their own Ageing Management Program and the corresponding Safety Requirements, like: Japan, Netherlands, Hungary, Czech Republic…

EDF PROCEDURE FOR AGEING MANAGEMENT

For EDF French PWR plants, the lifetime management policy of the nuclear power plants is based on four principles [3]:

- 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" is charged 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, 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.

Ageing management program review

The major objectives of these past 15-years are 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.

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

- prediction and detection, early in the SSC life, of degradations that can affect design rules (integrity of barriers) or safety function of the plant (final safety analysis report),
- 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:

- 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, the different French Codes & Standards, as RCC-M Code for Design and Construction of French PWRs and RSE-M Code for Surveillance in operation of French PWRs and the corresponding plant Final Safety Analysis Report (FSAR).

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 table with one line per component, structures, or element for each potential degradation mechanism. In the same time different other information 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)?

After the completion of a matrix (location versus potential degradation mechanism), 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: intermediate level to be moved to 0 or 2 shortly
- 2: prepare a specific justification report to confirm the continuation of operation, a Detailed Ageing Analysis Report (DAAR), similar to Time Limiting Ageing Analysis (TLAA)

A specific data sheet is attached to each line of the matrix in order to collect all the references used to complete the matrix.

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 permitted.

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

- 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

Synthesis report

This synthesis report has to collect the major information of the 2 previous steps: selection and report to justify continuation of operation. A comparison is done with existing maintenance practices for all components and structures. A set of recommendations for maintenance improvements is done to the Utility service in charge of "maintenance and ISI" program definition. All the recommendations are analyzed, including the economical aspect of the changes in order to update all the ISI and maintenance documents. All these reports and synthesis are transferred to each plant, in order to identify any particular aspect of each of them and to assure that all the recommendations will be implemented.

Major results of EDF AMP

The corresponding analyses have been done for EDF 3-loop plants (34 similar plants, oldest in operation since 1977). We considered more than 1500 safety class systems, structures and components (SSCs), we obtained around 500 lines in the cross table (1 line = 1 potential degradation in 1 location of an SCC) and we developed 12 DAARs: reactor pressure vessel and internals, pressurizer, main coolant pump, main coolant loop and auxiliary class 1 piping steam generator, containment, containment electrical penetration, nuclear civil engineering structures, cables, Instrumentation & Control (I&C).

The corresponding reports have been reviewed by French Safety Authority and after different meetings we have received a general agreement to move from 30 years to 40 years of operation. This agreement received in July 2009 has been associated to particular requirements:

- update of the cross table and associated Ageing Sheet every year, including any national or international field experience,
- update the DAAR every 5 years,
- developed a specific review of generic studies at each plant level to develop any specificity of the plant concerning AMP one year before the periodic shutdown,
- developed a concluding report in the 6-months following the plant back in operation to analyze consequences of all the information collected during the shutdown in term of AMP.

Same procedure is under application for EDF 4-loop PWR plants (oldest has 25 years of operation).

RESEARCH AND DEVELOPMENT TO SUPPORT EDF AMP

Many actions are going on in different direction to cover AMP and degradation understanding and modelling to perform some prediction and develop fitness for long term operation of SSCs.

In this presentation only R&D activities for metallic components is covered, nevertheless similar program s exist for Civil Engineering Structures, I&C components, cables…

3 directions for these R&D activities:

- the material degradation and associated material properties,
- the ageing mechanism models and the major parameter evaluation,
- the safety margins.

The different mechanisms concerned are:

- corrosions

- fatigue
- corrosion-erosion
- thermal ageing
- radiation embrittlement

with possible degradation interactions.

Material degradation and associated modelling and material properties

Different topics are covered:

- high irradiation level of RPV beltlines for 60 years of operation,
- corresponding toughness of the cladding,
- thermal ageing of low alloy steels and welds,
- consequences of heterogeneities in the underclad areas,
- Irradiated Assisted Stress Corrosion cracking, creep under irradiation, swelling, fatigue, loss of ductility of materials of RPV internals,
- Wear of stellite guide parts in RPV internals
- Air fatigue curve of stainless steel material, plus environmental effects
- Thermal ageing of cast duplex stainless steels and different welds, including dissimilar metal welds
- Fatigue crack initiation curves and crack growth curves for stainless steels and welds
- Stress corrosion cracking of cold work stainless sttel
- Stress corrosion cracking of Nickel based alloys (600 and 690): initiation and crack growth rates for penetration base metal and welds and steam generator plates
- High cycle fatigue of main coolant pump internals and shaft
- Erosion-Cavitation of pump wheel
- Strain ageing and thermal ageing of carbon steels
- Flaw accelerated corrosion: thinning rates
- Fatigue environmental effects for carbon steels and welds

Consequences of ageing mechanism on failure mode: models and major parameter evaluation

These different degradation mechanisms can lead to local thinning, cracks or loss of material properties. The degradation rate is generally expressed in thinning rate or crack initiation/crack growth. For the loss of material properties it's more the flaw tolerance of the component that can be strongly reduced.

The mechanical parameters used are generally the fracture mechanic parameters (K or J). The French RSEM Code [12] is extremely detailed and does not need any further development.

The remaining questions are:

- the plastic limit load for plastic instability of normal, thinned or cracked components,
- the toughness transferability from CT specimen to the real structure
- mismatch and dissimilar metal welds
- for brittle fracture: the warm pre-stress effect, the crack arrest, the effect of local brittle zone in low alloy steel
- the residual stress level and their effects on crack growth (corrosions), rupture in brittle regime or in ductile regime for low toughness materials
- the large ductile crack growth (on 10 mm or more)
- the rupture criteria of high toughness materials, like stainless steels or nickel based alloys

Safety margins

It's a very important issue to understand how the different uncertainties, in data or in models, can affect the ageing effect and the acceptable degradation.

For simple degradation mechanisms, using a limited number of data it's not a real concern. But for more complex situation moving from safety scenario, transient definition, flaw evaluation the final conclusion with all the models and parameters in the safety side it's impossible to reach a reasonable conclusion.

2 ways are under analysis in our R&D work:

- the partial safety factors
- the probabilistic evaluation of margins.

The bridge between deterministic and probabilistic approaches is a key issue for safety margin evaluation.

CONCLUSION

EDF has developed a general procedure for Ageing Management of safety class components. These program is applied to the 3-loop plants and regularly reviewed by French Safety Authorities.
This procedure is globally in accordance with IAEA Safety Guide recommendations.
In addition, an important R&D program is on going to understand and quantify the major degradation mechanisms and their consequences.

The major conclusions are clearly supporting the needs of international basic procedure and harmonization

REFERENCES

[1] IAEA Safety Standards- Ageing Management for Nuclear Power Plants- Safety Guide NS-G-2.12
[2] USNRC, "Generic Aging Lessons Learned (GALL) Report", NUREG-1801, rev.2, December 2010.
[3] C. Faidy, " French Procedure for Ageing management program of safety components", *ASME Pressure Vessel & Piping Conference*, Cleveland OHIO, USA, July 2003
[4] C. Faidy, "Ageing Management Program: Comparisons between EDF methodology and US GALL report", *ASME Pressure Vessel & Piping Conference*, San Diego, CA, USA, July 2004.
[5] C. Faidy, " Overview of EDF Ageing Management Program of Safety Class Components", *International Conference on Ageing Issue in Nuclear Power Plants* - NuPEER 2005 – Dijon France, June 22-24, 2005
[6] C. Faidy, F. Hedin, " EDF lifetime management of nuclear components : a safety and economical issue", "*PLIM-PLEX 2006*", Paris, France, April 10-11, 2006
[7] C. Faidy, "Aging management of EDF NPP : from the design phase up to end of life", *2nd international Symposium on NPP Life Management*, Shanghai, China, 15-18 October 2007
[8] D. Dallery, JJ Nicolay, " Ageing Management, In-Service Inspection and Exceptional Maintenance", *2nd international Symposium on NPP Life Management*, Shanghai, China, 15-18 October 2007
[9] C. Faidy, " Degradation Mechanisms – Overview in Connection with AMP", *ASME Pressure Vessel and Piping Conference* , paper PVP2007-26349, July 22-26, 2007, San Antonio, TX, USA
[10] C. Faidy, "EDF Ageing Management and International Cooperation", *ASME Pressure Vessels and Piping Conference*, paper PVP2009-78024, July 26-30, 2009, Prague, Czech Republic
[11] C. Faidy, " Ageing Management Program: A key Issue for Operating plants and New Design", *20^{th} International Conference on Structural Mechanics in Reactor Technology*, SMiRT 20, Espoo, Finland, August 9-14, 2009
[12] RSE-M Code, "Rules for In-Service Inspection of PWR Nuclear Power Plant Components", Appendix 5, 2010 Edition, AFCEN, Paris.
[13] RCC-M Code, "Design and Construction Rules for Mechanical Components of PWR Nuclear Islands", 2010 edition, AFCEN, Paris.
[14] C. Faidy, " EDF Ageing Management: Status and Ongoing Developments", *ASME Pressure Vessels and Piping Conference*, paper PVP2011-58058, July 17-21, 2011, Baltimore, Maryland, USA

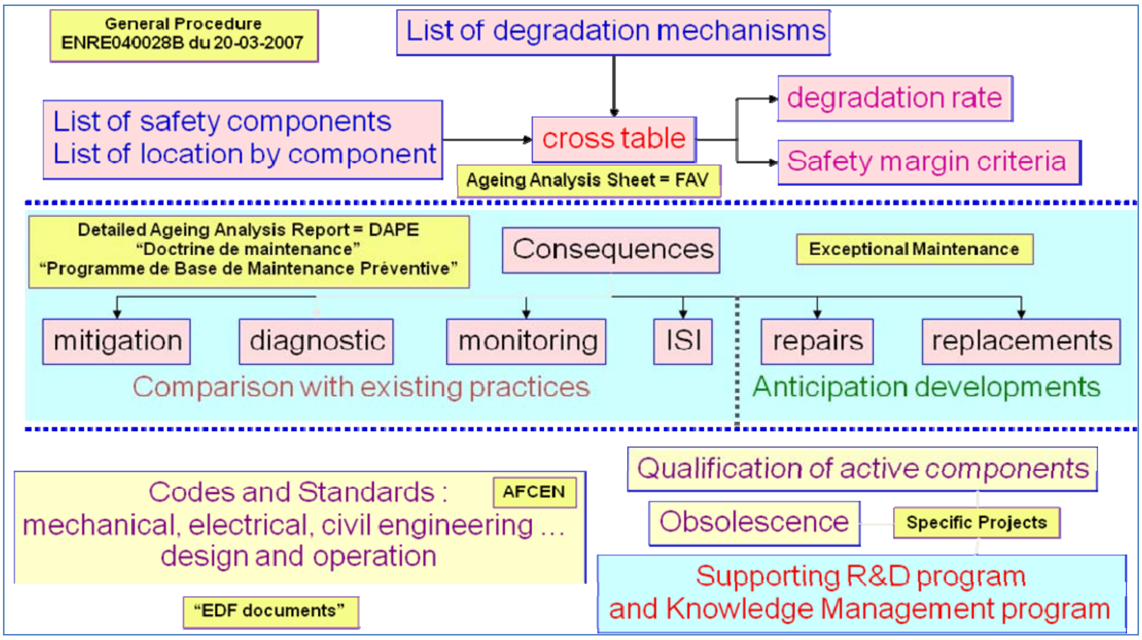

Figure 1 : General overview of EDF AMP

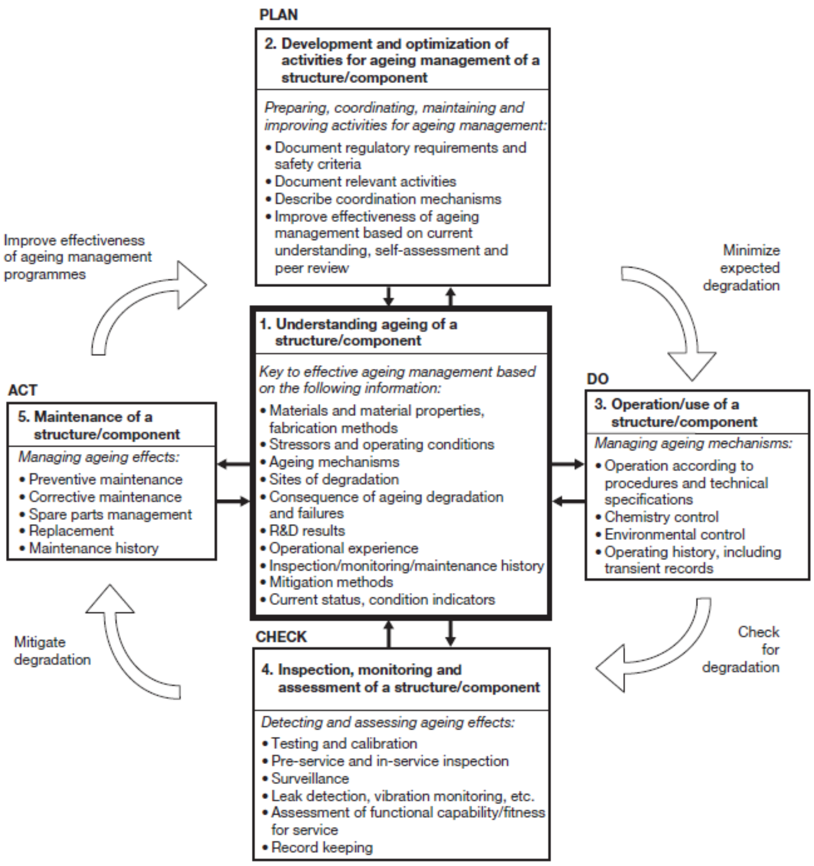

Figure 2: The IAEA PLAN-DO-CHECK-ACT diagram for AMP

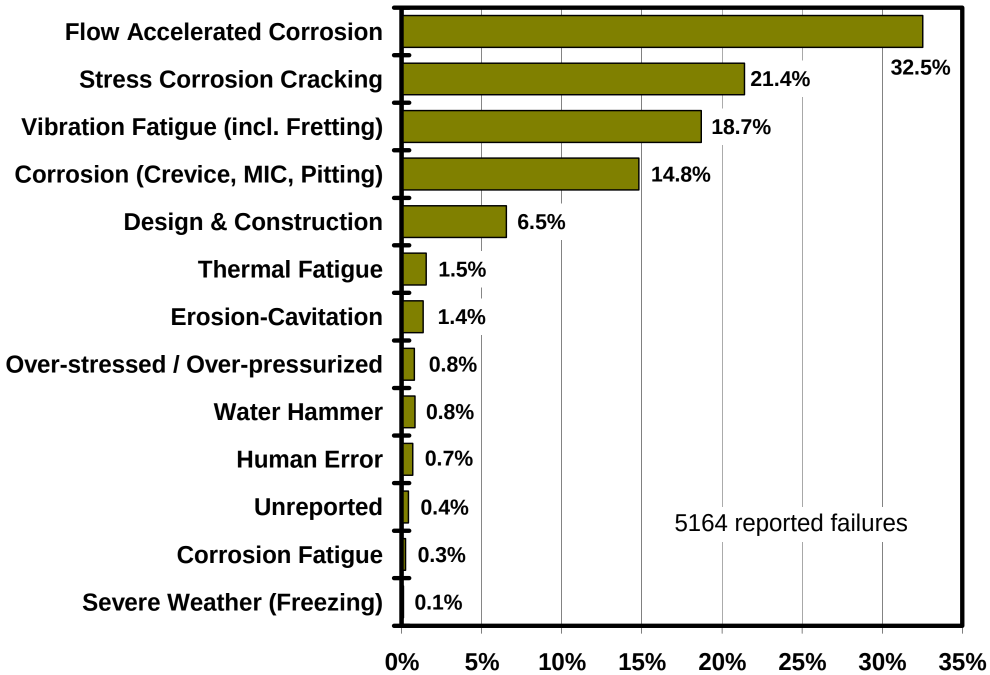

Figure 3 : Major degradation mechanisms encountered in piping systems (from OPDE-OCDE data bank)

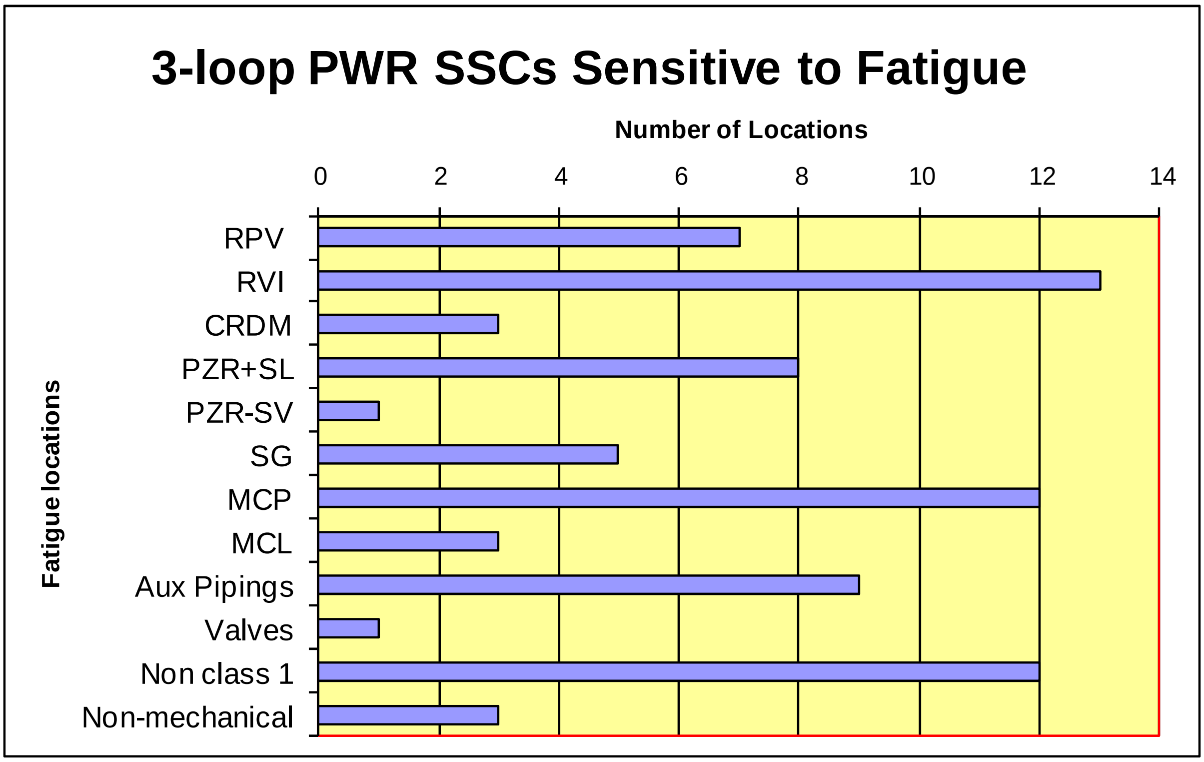

Figure 4: Number of locations potential sensitive to fatigue for EDF 3-loop PWR

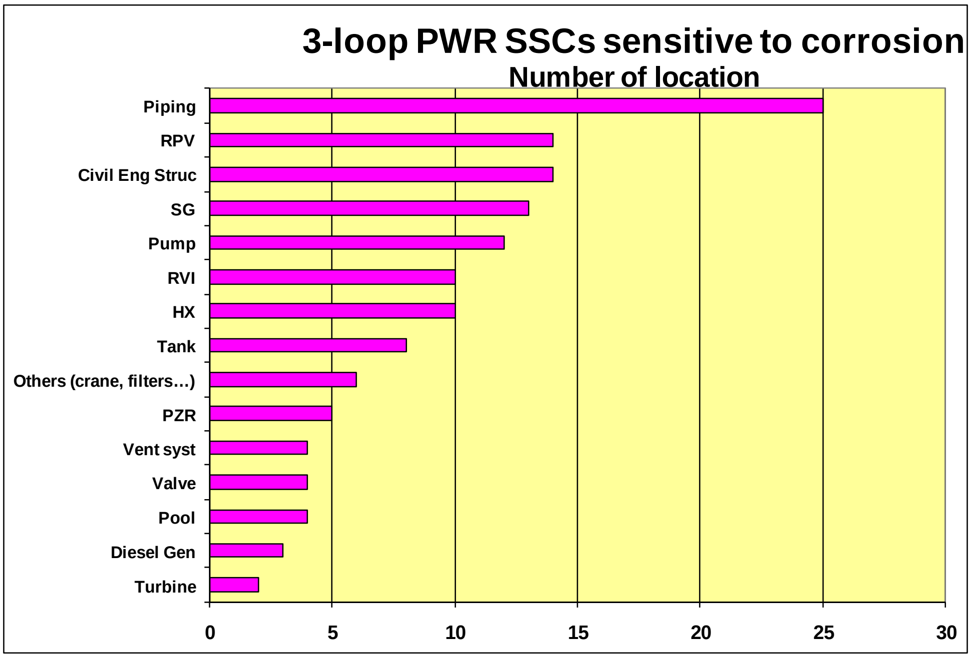

Figure 5: Number of locations potential sensitive to corrosion for EDF 3-loop PWR

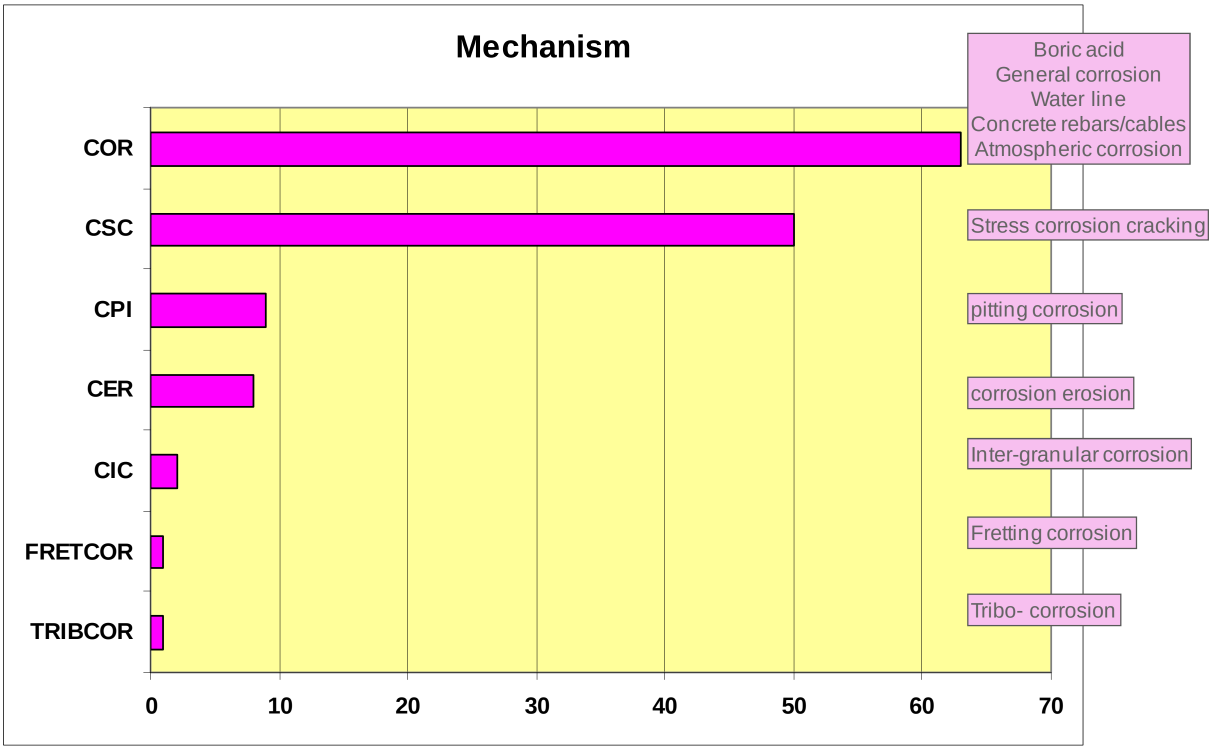

Figure 6: Number of locations potential sensitive to different corrosion mechanisms for EDF 3-loop PWR