AGEING MANAGEMENT, IN SERVICE INSPECTION AND EXCEPTIONAL MAINTENANCE

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Abstract

Actions implemented by EDF in the field of maintenance in order to control the ageing of Nuclear Power Plants (NPPs) Structures, Systems and Components and to ensure an operation of NPPs in compliance with safety requirements are described. Routine maintenance, exceptional maintenance, in service inspections associated with an efficient monitoring and a thorough analysis with the experience feedback, contribute to this control and has to be adapted to each component, taking into account the ageing phenomena brought into play. Several examples implemented by EDF on Nuclear Island or Conventional Island equipments are introduced : Reactor Vessel Heads replacement strategy, Steam Generators replacement strategy, I&C systems long term maintenance strategy, Generator Stators refurbishment strategy. Maintenance strategies are based on in service inspection activities, using qualified examination methods.

1. Introduction

EDF PWR fleet consists of 58 Units in operation for an installed capacity of 63 GWe. At the end of 2007, this fleet has an average age of approximately 23 years, the youngest unit 8 years and the oldest 30 years. EPR unit construction has begun at Flamanville site.

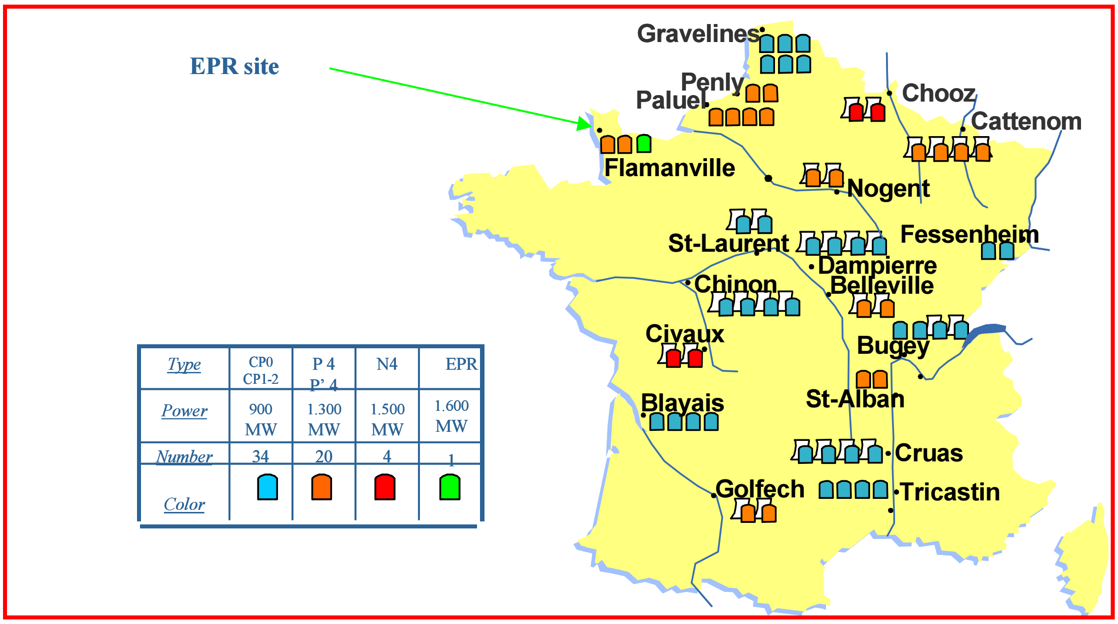


FIG. 1 EDF NPPs Fleet

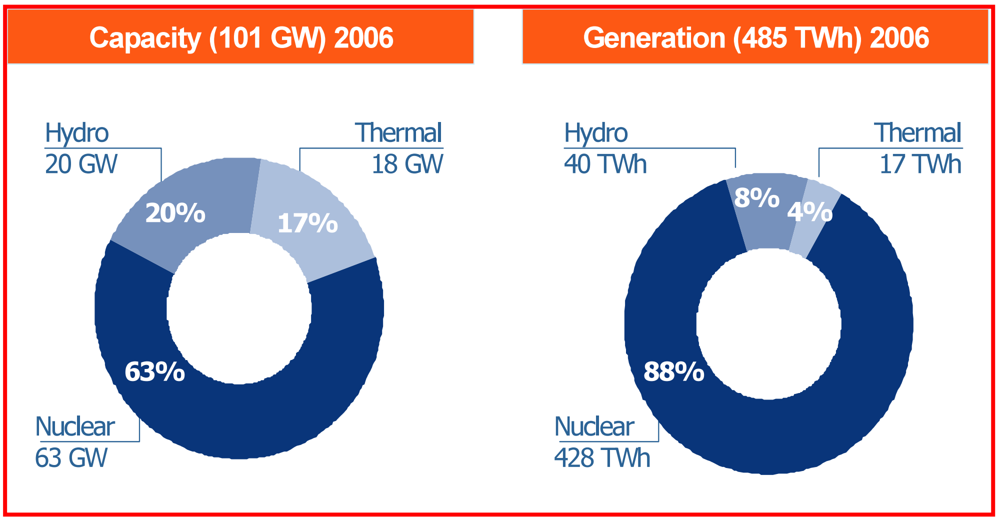


FIG. 2 : Structure of EDF generation capacity in France

More than 95% electricity output is CO2 emission free.The performances of the NPPs fleet, for the short term but also for the mid term and long term, constitute a major stake for EDF.

Environment effects and various types of stresses (mechanical, thermal, chemical, irradiation...) cause ageing of NPP equipments. If we do not implement at the appropriate time the actions necessary to know the accurate status of the equipments and the answers to control ageing phenomena, those can in the long term affect the performances and the duration of Unit operation.

The control of structures, systems and components ageing is based at first on the quality of their design and their fabrication which makes possible to preserve, as far as possible, from detrimental ageing phenomena. If they cannot be isolated, adapted in service inspection methods are defined in order to evaluate ageing effects and to guarantee safety margins during operating time.

Then, this control is based on the quality of the Units maintenance and operation. It is necessary to have a prospective vision of possible degradations in order to anticipate and to implement, advisedly and at the appropriate time, the adapted answers. Such vision is important to guarantee the quality of maintenance and operation, the availability of the Units all along their life time, in compliance with the safety requirements,
For EDF, such prospective vision and anticipation are all the more necessary since the standardization of its NPPs fleet is a lever for performances but also a possible source of vulnerability compared to generic degradations.

During Units operation, some technologies used at the time of the construction of the NPPs can disappear. Changes in industrial network also induce a risk of disappearance of spare parts or rare competences. Such risks of obsolescence relate especially to I&C and electrical components, but also exist for some mechanical components answering requirements specific to the nuclear industry.

To avoid these threats, EDF supervises the durability of sensible industrial competences, in a prospective way, in order to define industrial policies as regards engineering or maintenance activities,...and to ensure, with its industrial partners, the durability of the nuclear fleet under the best conditions of safety and cost, for the lifespan of the Units.

These provisions of industrial strategy are supplemented by a process for risk management regarding Spare Parts procurement. All obsolescence items are registered in a national database : for each obsolescence issue, the best possible strategy is sought, on a case by case basis: preventive stock implementation, search for substitute component, system or equipment modification.

2. EDF Maintenance Policy

2.1. Routine Maintenance

EDF maintenance policy comprises three key objectives :

- Give priority to safety,
- Improve the competitiveness of the nuclear kWh,
- Prepare for the future, enabling an operating life time of at least 40 years for the NPPs fleet (according to french regulation, a Periodic Safety Review has to be performed every 10 years).

EDF maintenance policy is based on a routine maintenance to maintain the functional capacities of equipments and the availability of the Units, in compliance with safety requirements.
Since 1995, the routine preventive maintenance and the associated surveillance are piloted and optimized compared to the stakes in safety and in competitiveness. After a first phase of optimization using RCM analysis, EDF develops for several years conditional preventive maintenance, based on strengthened diagnosis/prognosis and conditional preventive maintenance on a sampling basis, taking benefit of the standardized fleet of Units.
In every case, the definition of this routine optimized preventive maintenance requires the knowledge of the functional consequences of the failures and the utilization of the experience feedback, taking into account lab examination of used components and validation of non destructive examination methods.

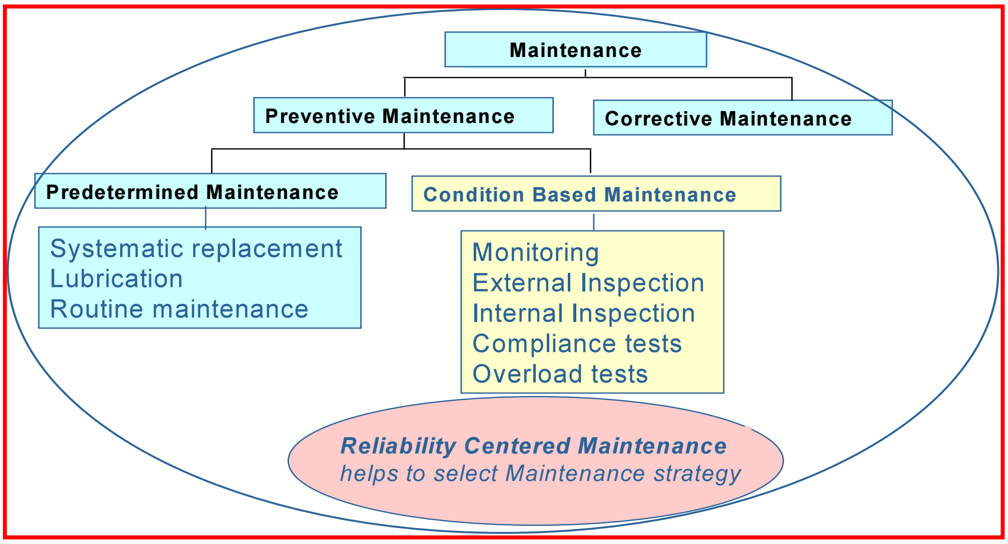


FIG. 3 Routine Maintenance

For active equipments, condition-based maintenance is based on operating parameters monitoring and periodic health check-up.

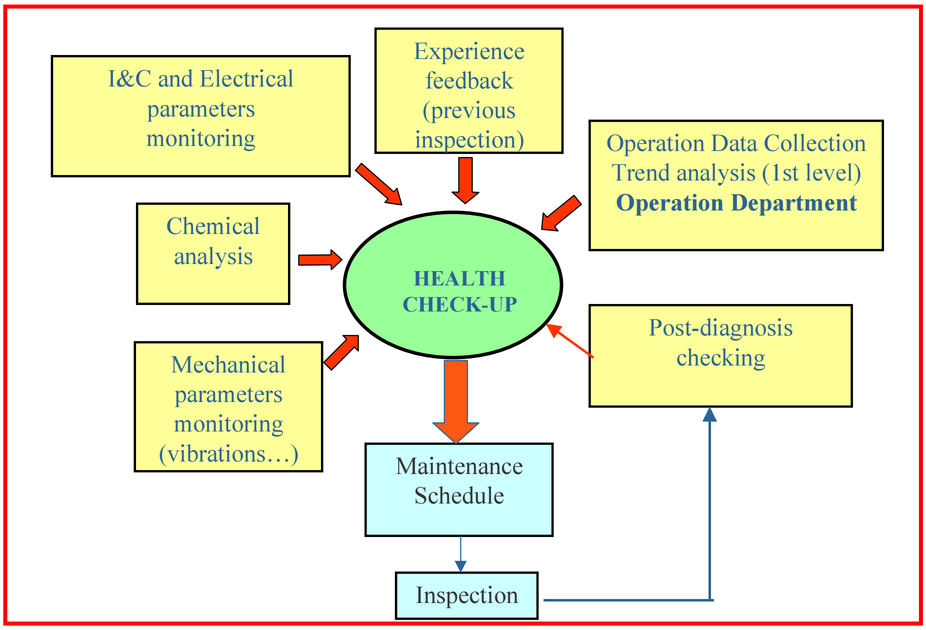


FIG. 4 Health Check-up

This routine maintenance results in various actions such as adjustments, replacements of wear parts, functional or equipment modifications, repairs, … But to face certain ageing phenomena occurring in a irreversible way in the course of time, it is necessary to complete it by an exceptional preventive maintenance of bigger scale.

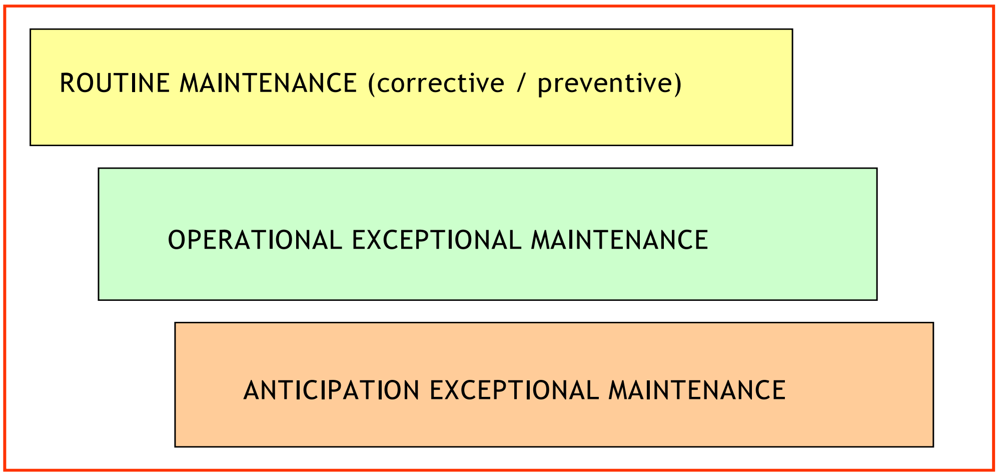


FIG.5 Fields of maintenance

2.2. Exceptional Maintenance

Operational Exceptional Maintenance consists of operations carried out only once (it is the objective) during the lifespan of the Units. They are implemented to control proven or potential degradations, in anticipation, concern a significant part of the fleet and present important industrial stakes (costs, dosimetry, resources, outage duration…) ; they are thus planned at the fleet level on several years.

Anticipation Exceptional Maintenance includes actions such as identification of potential exceptional maintenance activities and definition of strategy adapted to the risk. Each topic is conducted through a dedicated Project; an anticipation file is prepared with :

- Technical-economic analysis of the stakes
- Choice between different strategies
- Feasibility study of the replacement/repair
- Possible order for Spare Parts and appropriate tools procurement
- Definition of the replacement/repair procedures
- Cost evaluation of the maintenance activities

At the national level, a Maintenance Committee is in charge to review the proposal and the technico-economic file prepared by the Project team. This Committee is chaired by a Nuclear Operations Division Top Manager and members are designated from NPPs, Engineering Division, Financial Department and R&D Division.

Exceptional Maintenance relates primarily to the large components of the Nuclear Island and Conventional Island : steam generators, turbines, generators, condensers, control systems, civil works,… and requires:

- a capacity of degradation forecast and repairability/replaceability anticipation, needing R&D and engineering works,
- a capacity of decision making and programming economically relevant in relation to the technical end of Units lifetime and the possible increase of their performances; it is important to have a visibility for the next 20 to 30 years for the choices of large investments to be studied.

2.3. Examples

To illustrate this policy, several examples implemented by EDF on Nuclear Island or Conventional Island equipments are described :

- Reactor Vessel Heads replacement strategy.
- Steam Generators replacement strategy.
- I&C systems long term maintenance strategy.
- Generator Stators refurbishment strategy.

2.3.1. Reactor Vessel Heads replacement strategy

After leakage detection during hydrotest in 1991 on Bugey 3 RVH adapter, EDF initiated a long term strategy in order to deal with this issue, in compliance with safety requirements. As soon as 1993, after degradation characterization and safety evaluation, it was decided to replace all RVH equipped with alloy 600 adapters on the 54 operating Units. Such decision was justified by :

(1) Technical analysis showing that stress corrosion cracking on alloy 600 adapters was a generic and inescapable issue on all RVHs, and thus, industrial capacities to replace RVHs were to be considered for 10 – 20 years,

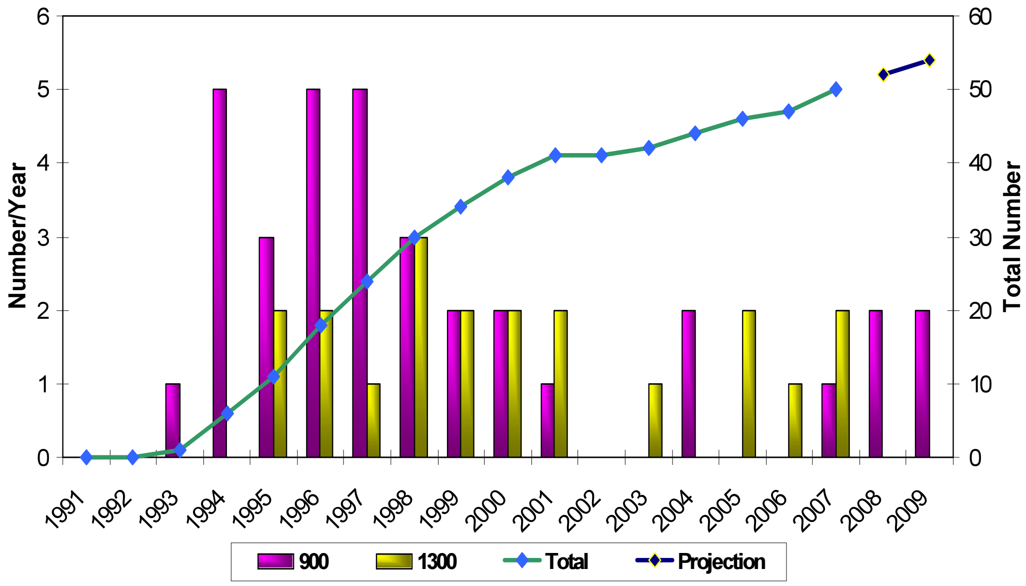
(2) Other options (adapter repair or adapter replacement) were more penalizing on radiation protection, outage management and financial aspect.

(3) The robustness of the RVH replacement option (using new RVH equipped with alloy 690 adapters), with respect to the lifespan of the Units.

Today, 50 old RVHs have been replaced and the 4 last old RVHs will be replaced before 2010. The replacement schedule was carried out, according to ISI results, in compliance with safety criteria (residual ligament size), and often in strong anticipation due to industrial optimization of replacement activities. On some Units, RVH replacement was combined with CRDM replacement (in case of CRDM with large number of operating steps).

FIG. 6 New RVH for 1300 MWe Unit

FIG. 7 RVH Replacement Program



2.3.2. Steam Generators replacement strategy

To guarantee the safety and to limit the risk of forced outage, Steam Generators management includes current maintenance and operation activities:

- Continous monitoring of primary to secondary leakage during operation (N16 channels),
- NDE of SG tube bundle (using qualified methods) during refueling outages and preventive plugging of tubes exceeding repair criteria,

- Chemistry optimization on the primary and secondary sides,
- Cleanness on the secondary side (loose part prevention, sludge lancing…),
- Condenser material optimization.

From 2007, chemical cleaning is also performed on SGs equipped with broached Tube Support Plates (TSP), in order to avoid TSP flow hole clogging.
SGs equipped with alloy 600MA tube bundle appeared particularly sensitive to PWSCC and ODSCC. Probabilistic evaluation is performed to predict the end of SG technical lifetime : if SG plugging rate is expected to reach the maximum value in the future, Exceptional Maintenance (SG replacement) has to be prepared.

FIG. 8 New 900 MWe SG

Since the first SG replacement in 1990, SG replacement has been performed on 16 of 25 900 MWe Units initially equipped with alloy 600MA SGs. It is expected to complete the replacement of 600MA SGs on all Units in the next ten years (about one SG replacement per year is planned).
In order to optimize industrial resources and to smooth replacement program (SG replacement needs about 100 M€ investment per unit), some SG replacements have been realized in anticipation compared to the SG technical lifetime.

2.3.3. I&C systems long term maintenance strategy

In addition to the possible needs for I&C evolution due to performances increase, the strategy is based on partial and progressive renovation advisedly, according to periodic I&C ageing review. Obsolescence management (for hardware and software components) and skills management are deciding issues, in comparison with the stakes (I&C renovation costs about 60 M€ per Unit). For I&C systems and components, the axes followed by EDF for ageing management are the following :

(1) to observe, expect and anticipate I&C components ageing ;
(2) to have a strategic stock of spare parts allowing to meet the needs for current maintenance for several decades ;
(3) to maintain a close relationship with I&C Suppliers for experience feedback analysis, skills management and logistics maintenance, through durability contracts.

FIG .9 Main Control Room (1500 MWe Unit)

As an example, for 900 MWe serie, the ageing management review of I&C equipment was performed in 2002-2003, seven years before the first of kind 3rd 10-year outage planned in 2009. I&C equipments which could not reach the 4th 10-year outage are replaced during the 3rd 10-year outage.

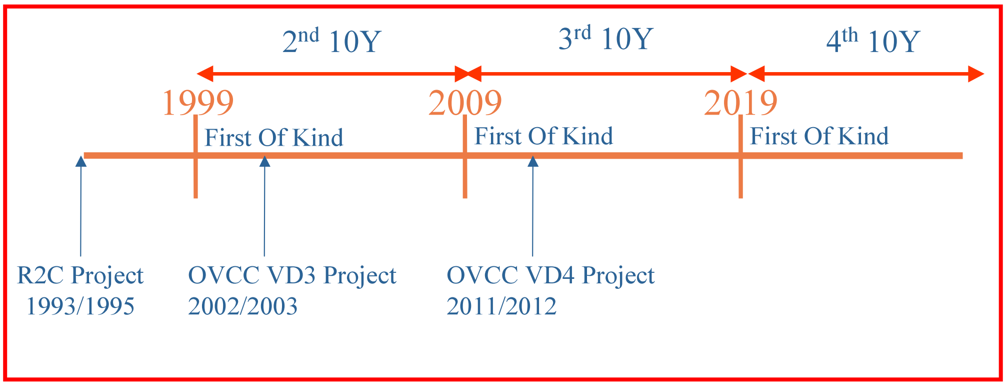


FIG. 10 I&C progressive renovation according to 10Y outages schedule

R2C "Rénovation du Contrôle-Commande", OVCC "Observatoire du Vieillissement du Contrôle-Commande" : I&C ageing review Projects
VD3 : 3rd 10-year outage; VD4 : 4th 10-year outage
Further to OVCC ageing review, several I&C systems are planned to be totally or partly replaced, on 900 MWe Units, during the 3rd 10-year outages : Nuclear Instrumentation System, In-Core Instrumentation System, Rod Control System, Turbine Governing System…Considering the different series (900, 1300, 1500 MWe), preparation of I&C refurbishment during the 10-year outages is a permanent activity.

2.3.4. Generator Stators refurbishment strategy

Main degradation phenomena met by EDF on Generator Stators are the following :

- Isolation decreasing caused by water box leakage

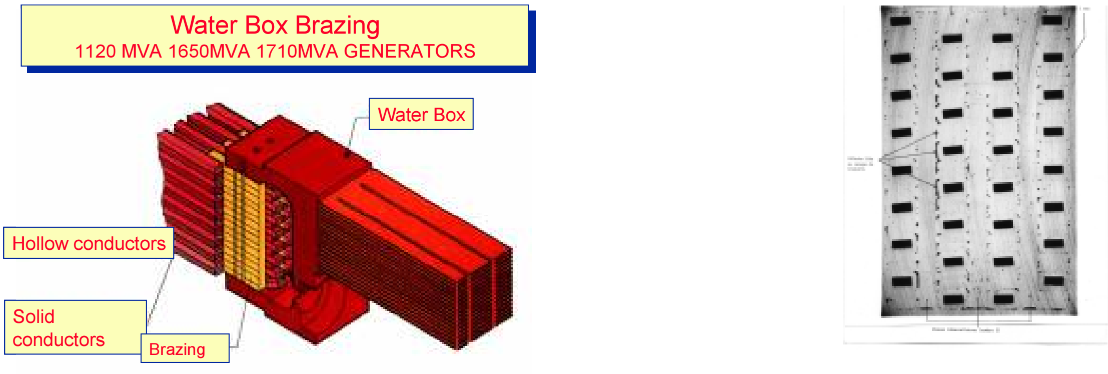
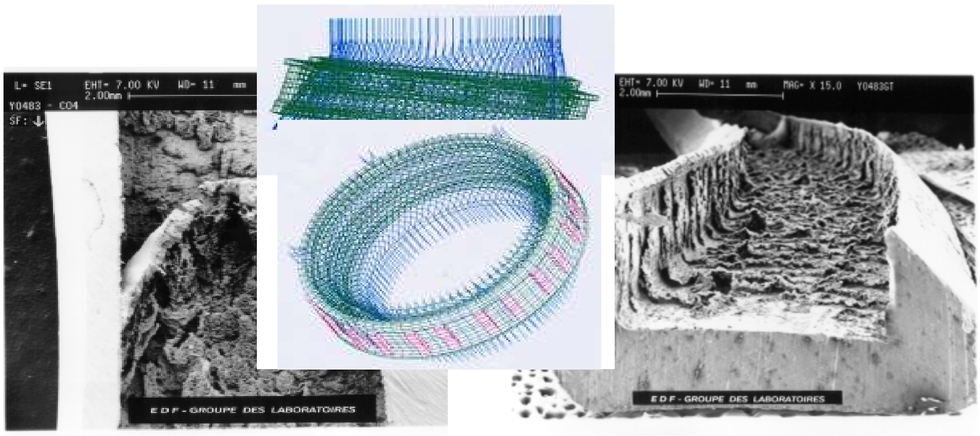


FIG. 11 Water Box Leakage

- End Winding Vibration

FIG. 12 Stator End Winding Vibration



- Hollow conductors plugging

FIG. 13 Hollow conductor plug formation

- Stator core ageing (core looseness, lamination short circuit, external cause).

Current maintenance activities are performed on Generators in order to monitor in service behaviour of each equipment : isolation measurements, humidity measurments, end winding vibration monitoring, lamination isolation tests, core tightness tests.
Repair methods are used to face some degradations, such as : stator bar replacement, water box laser repair, chemical flushing… but, in the course of time, more important maintenance becomes necessary.

Depending on the monitoring results, the repair history and the Health Check-up on each Generator, Generator Stators are classified in different groups (group A : good stator, group B : lightly degraded stator, group C : strongly degraded stator). Based on this classification, an Exceptional Maintenance program has been defined which consists of Stator rewinding or replacement, with priority given to the most degraded Stators, in order to prevent unplanned forced outages.

On 900 MWe Units, such Exceptional Maintenance is planned on 22 Generators Stators for the next 10 years. This program is updated every year, according to monitoring/inspection results and health check-up conclusion.

2.3.5. Examples related to Anticipation Exceptional Maintenance

Examples of anticipation actions are described hereafter, regarding components of the main primary circuit. In addition to ISI activities, the purpose for EDF is to be ready to repair or replace components if any ageing phenomena (due to PWSCC, thermal fatigue…) is detected.

2.3.5.1. Inspection and replacement/repair of parts of auxiliary circuits of the primary circuit

CVCS charging line nozzle has been identified as a mixing zone with possible thermal fatigue. NDE method has been developed as well as repair and replacement process. Taking benefit of Fessenheim 1 SG replacement, CVCS nozzle has been taken from the plant and examined in hot laboratory : no crack was detected.

FIG. 14 Destructive examination of Fessenheim 1 CVCS nozzle

2.3.5.2. Reactor Vessel BMI penetration repair (alloy 600 zone)

In order to anticipate any ageing phenomena on BMI penetration, ISI program is performed on EDF Units. Despite no crack has been detected, several repair methods are developed and qualified :

- BMI penetration plugging,
- BMI penetration welding repair,
- BMI penetration replacement.**In Service Inspection**

The maintenance policies carried out by EDF, the knowledge of the accurate status of Structures, Systems and Components but also the safety of the operating Units are based on coordinated, periodic and effective ISI programs implementation.

Based on a broad panel of Non Destructive Examination (NDE) techniques, the owner can adapt to the required objective the performances of these techniques. Visual examination, Dye Penetrant test, Ultrasonic test, Eddy Current test, Radiographic test, Acoustic test, Hydrotest are thus usually used on the sites.

In service inspection programs are defined according to three main principles:

(1) for in-depth defense, a certain number of zones are inspected in order to confirm analysis carried out showing absence of risks; ten-year outages are generally the time chosen to perform those inspections because the results contribute to the demonstration of safe operation for the next ten years of operation,

(2) further to analysis showing that certain zones have to be considered at risk, either because ageing phenomena can appear there, or because in service loads could lead to evolution of manufacturing defects; design reports are the origin of these inspections, fatigue phenomena are generally sought,
(3) regarding defects due to ageing phenomena, the objectives are to detect these defects then to characterize them (location and dimensions) in order to be able to evaluate the potential harmfulness of these defects and to adapt the maintenance policy.

The French regulation, especially related to pressure components, defines partly ISI programs because they aim at securing pressure risk and contribute to the industrial safety. The Decree of November 10, 1999 for the PWR Main Primary and Secondary Circuits, the Decree of March 15, 2000 for the Conventional Island Circuits and the Decree of December 12, 2005 for the circuits which can contain radioactive fluids are the main rules to be taken into account. They specify the requirements in term of NDE qualification, of ISI indications follow-up, and of ISI programs content and examination minimal periodicities.

EDF organizes its policy on ISI matter around "doctrines de maintenance" written for all important equipments either from a safety point of view, or with technico-economic, environmental or availability stakes. Each doctrine is based on the regulation in force, the design engineering, the internal/external experience feedback, the acquired knowledge and particular analyses. It is thus possible to propose for each one of these equipments an ISI program and a maintenance policy.

Implementation of ISI programs is typically defined on a decennial basis but, depending on the evaluated risks, shorter periodicities can be proposed.
Some examples, for each of the three main principles quoted hereabove :
(1) UT examination of Reactor Vessel welds not subjected to irradiation carried out at the time of the ten-year outages, visual examination of the civil works structures such containment or cooling tower,…
(2) NDE of irradiated Reactor Vessel parts, in order to prevent the risk of non-ductile failure, NDE of certain zones subjected to fatigue on the Pressurizer, and also MT examination of turbine blades, isolation measurements of Generators Stators...
(3) In service follow-up of alloy 600 RVH adapters, the program being adapted to the stress corrosion cracking kinetics and to the RVH replacement schedule, in service follow-up of circuits subjected to Flow Accelerated Corrosion using thickness measurements, the localization of zones to be inspected and the periodicity of measurements depending on the studies carried out and the previous results.

4. Conclusion

Safety and competitiveness of EDF NPPs fleet in the mid term and long term are part of the same objective for Units life time management.

In this respect, anticipation based on improvement of knowledge, adapted and effective ISI, monitoring and analysis of the operating experience feedback and the industrial capacities are today necessary to consolidate the visibility on lifetime of the main equipments and to prepare choices of investments and industrial strategies.