Maintenance Optimization through Risk Based Ageing Management Program

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Abstract

With increasing demand for energy and the need to control energy costs, many nuclear energy producers choose to extend the lifespan of their existing infrastructures while ensuring operation safety. The success of this decision requires a high level of expertise and know-how in managing the infrastructure life cycle. Oxand has developed and implemented dedicated integrated solutions to assist in managing the ageing of infrastructure over its life-cycle: operation, license renewal application and extended lifespan. These solutions enable to anticipate and optimize the maintenance of the infrastructures thanks to relevant Ageing Management Programs integrating owners' issues such as safety and availability.

1. Introduction

Nuclear Power producers operate a large number of civil engineering infrastructures which they have to maintain. As long as existing infrastructures were in their "youth" (slow to moderate ageing phase), mostly minor damages appeared and they could be dealt with a curative strategy and maintenance budgets could be planned on recurrent costs.

With the ageing of the structures, damages and corresponding maintenance costs display a sharp increase. Furthermore, as budgets become stringent it is impossible to refurbish all the various structures. It becomes therefore important to anticipate and evaluate the ageing of infrastructure to appropriately quantify maintenance needs. Most nuclear power plants need to renew their operating license and demonstrate their appropriate ageing management to the local nuclear safety commission.

Traditionally, civil engineering infrastructures have been considered to have long life expectancies so reference documents and regulations provide rougher guidelines than for mechanical engineering ageing management. However, it becomes clear today that civil engineering infrastructure may drive the decision to extend the lifespan of a nuclear power plant, due to the cost of replacement and production unit shutdowns necessary for important maintenance works on strategic assets such as reactor building or reinforced concrete pipes.

This article describes the methodology developed by Oxand to help owners evaluate the residual life expectancy of the essential components of production units and develop their Ageing Management Programs. The article also presents possible improvements of classic Ageing Management by integrating all owners' issues in order to define adequate maintenance strategy during the extended lifespan with a risk-based management approach.

Indeed, in the particular case of long lifecycle civil works, performance management might not be appropriate since modifications to existing structures are often impossible to achieve without a complete rebuilt. However, risk-based management can provide a way to prevent and/or mitigate the possibility of adverse or unexpected situations arising from ageing asset and producing unacceptable consequences.

On the other hand, components that can be more easily repaired and/or replaced (mechanical or electrical components) can support a performance-based management that aims at increasing the efficiency and/or rate of success of the expected functionalities of a system.

2. Ageing Management Program

Ageing management is an important factor when considering long time operation (LTO) of a Nuclear Power Plant (NPP). Physical ageing of structures, systems and components (SSCs) can degrade their performance and impact safety. Ageing management helps ensure that SSCs remain capable of performing their required safety functions [1][2]. Thus, it is necessary to detect ageing effects of SSCs, address associated reductions in safety margins and take corrective actions before there is loss of integrity or functional capability of the structure.

The key to creating an effective ageing management includes five steps. These are 1) understanding the ageing structure, 2) coordinating, integrating and modifying existing programs or creating new programs 3) minimizing expected degradation of a structure through careful operation in accordance with operating procedures and technical specification, 4) inspecting and monitoring the structure to detect degradation and to determine type and timing of required corrective actions, and 5) amending the degrading component by maintenance and design modifications, component repair and replacement of a structure.

A methodology for the integrated plant assessment has been elaborated for a Belgium nuclear energy producer, taking into account civil works' particularities and compliant with IAEA and US NRC standards:

- Each step of development and implementation of ageing management recommended by the international guidelines is followed;
- The Report and all produced tables respect IAEA and USNRC templates (e.g. the ten paragraphs of the ageing management program);
- All ageing mechanism identified in reference documents are analyzed (GALL report, EPRI);
- Actions defined in the ageing management programs comply with safety regulations (USNRC regulatory guide, ASME code, etc.).

This methodology is composed of six steps:

1) Scoping
2) Screening / Ageing Management Review
3) Analysis of existing programs
4) Condition assessment
5) Ageing Management Program
6) Final review and evaluation report.

The "Analysis of Existing Programs" and the "Final review and evaluation report" are not mentioned in IAEA guideline. The first one aims at improving actions carried out by the power plants by comparing them with standards and adding them to Ageing Management Programs. Furthermore, this step enables to share operational experience of the owner's various power plants.

One of the main objectives of the last step “Final review and evaluation report” is to apply Ageing Management Programs to each structure. Indeed, an AMP describes preventive and corrective actions which should be implemented to manage an ageing mechanism, but the final action and its frequency (eg. every year, every five years) depends on the current condition of the structure, its environment and its accessibility condition.

These steps are relatively common in the process of integrated plan assessment and similar to the mechanical one but the civil works particularities lie in condition assessment which is described in the following.

3. Condition assessment

3.1 Regulation

Although condition assessment is key for deciding of the lifespan extension of infrastructure, reference documents (IAEA, NRC, EPRI) do not provide details on what kind of condition assessment should be made for civil works. Owners can choose the level of detail they want, the level of justification of current condition and the integration or not of predictive analysis. However, the more precise the condition assessment, the more relevant the Ageing Management Program will be. Oxand developed a methodology for Condition Assessment and applied it to a strategic asset (the reactor building), before applying it to the rest of civil engineering systems.

3.2 Condition assessment methodology

The methodology has been developed to fulfill the owner’s needs for the condition assessment essential to the license renewal application and for optimizing the maintenance over the extended lifespan.

This methodology takes into account two approaches: one focused on causes and defects (standard approach), and the other focused on consequences and threats. The first one is mostly based on visual inspections and identification of potential ageing mechanisms. The other method is used to assess what kind of failures may happen over the extended lifespan in order to anticipate relevant measures and justify appropriate investment.

The methodology also includes the identification of accessible and inaccessible zones. Indeed, the management of inaccessible zones is quite different from accessible ones because visual inspections cannot be planned and corrective maintenance is difficult or impossible without the production unit shutdown. In this context, it is important to identify threats or failure modes and their condition of occurrence (accidental load, permanent load) in order to anticipate some actions (complementary studies, preventive actions) and to justify them. Indeed, this approach leads to the demonstration of efficient and robust ageing management of inaccessible zones which are often neglected.

Another aspect of the methodology is the identification of the ageing mechanism’s kinetics that may influence the frequency of preventive actions. For example, if a study demonstrates that corrosion kinetic is very low, the frequency of visual inspection may be reduced, and resources may be used for other maintenance activities.

Finally, the methodology evaluates the level of uncertainties. Uncertainties are due to lack of data (mix of concrete for example), lack of inspection (for inaccessible zones for example), or lack of international feedback experience (level of residual prestress of concrete is for example difficult to evaluate without a high level of expertise). These uncertainties have to be identified and some measures may be taken to reduce them, like one-time inspections or complementary studies.

When uncertainties are high, in the context of license renewal application, a safety principle is applied, considering the most penalizing assumptions. These assumptions may highly increase costs of maintenance (through unnecessary actions) or induce unit shutdowns. Thus, in the context of life extension (for which availability and costs have to be optimized while ensuring good safety condition), risk analysis and risk management approaches as described below in the article are recommended, in particular to deal with the uncertainty level.

This approach enables (1) the identification of uncertainties, (2) the evaluation of uncertainties' level and their impact on safety margins, (3) the identification of actions to reduce these uncertainties or to control them so as to avoid unit shutdowns in particular. Indeed some uncertainties may be acceptable because they don't impact intended functions, whereas others have to be reduced by further studies or inspections in order to either reduce the lack of knowledge or demonstrate that even with penalizing assumptions safety margins are respected.

The following section describes some complementary studies which can be recommended after the condition assessment to reduce uncertainties.

3.3 Identification of necessary further studies

Two common ageing mechanisms can impact the mechanical behavior and therefore the life expectancy of civil works of nuclear power plant: corrosion and prestressing loss.

Once corrosion starts, it leads to a progressive decrease of rebar section or thickness. An important decrease will impact on the mechanical resistance of the structure and may require extensive repairs, expensive in terms of both time and money. That is why corrosion is considered to be so critical and an efficient ageing management plan has to be developed, especially for inaccessible structures (e.g. buried pipe).

During the lifespan of prestressed structures, the tension in tendons decreases due to delayed phenomena in materials (concrete shrinkage and creep, steel relaxation). The prestressing tendons' role is mostly to ensure the structures resistance to accidental load (internal overpressure…). These accidents may occur during lifespan, so estimating the residual prestressing level and its evolution is essential to justify that a high level a safety may be maintained during extended lifespan.
To address these issues, some complementary studies can be done like ageing simulations and finite elements modeling.

A software has been developed to assist consultants in their studies on the predictive evaluation of the behavior of concrete subject to the effects of various aggressive environments. The software simulates the deterioration of reinforced concrete structures due to two main phenomena that impact life-time: corrosion of steel reinforcements due to chloride attacks or carbonation and leaching. The software is based on a corrosion model defined in Ilie Petre-Lazar's thesis [3]. It has been validated by comparing the estimated prognosis with experimental data collected over 20 years as part of several research programs (e.g. corrosion of structures under different aggressive environments : saline, chemical, marine) [4][5].

To simulate deterioration, various input data are necessary:

- Concrete cover
- Chloride diffusion coefficient
- Chloride binding coefficient
- Average humidity
- Surface chloride concentration
- Concrete compressive strength.

Probabilistic studies can be done, based on the data from the owner or resulting from our database, to account for uncertainties about these parameters.

This kind of simulation enables the assessment of the frequency of failure modes, by calculating residual estimated mechanical resistance and comparing it to the required resistance in terms of safety. Thereby, the owner is able to demonstrate that an ageing mechanism does not impact the structure's functions over its extended lifespan, or he can adapt the frequency of preventive actions.

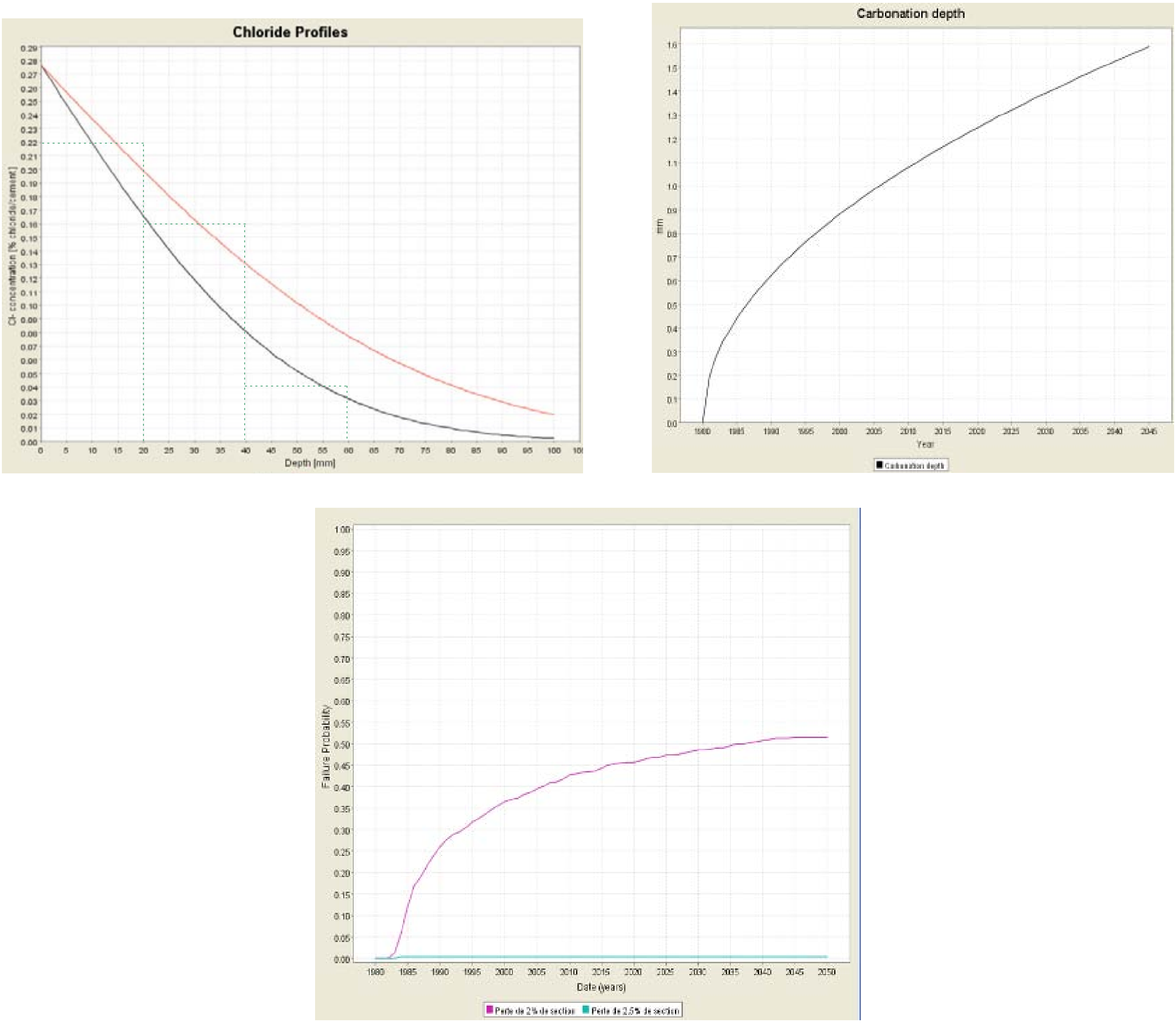

Figure 1 : Predictive simulation of corrosion with SIMEO™ Consulting Tools (Chlorides Profiles; Carbonation depth/ time; Failure probability/time)

In some cases, ageing simulations show that corrosion or other ageing mechanisms may impact the mechanical condition of the structure. Furthermore, experience feedback on nuclear containment shells shows that the impact of some ageing mechanisms such as creep of concrete are much higher than the original estimation, thus, owners need expertise to review design hypothesis and to assess the real condition of the structure.

Finite element modeling enables the quantification of risks and the demonstration that present and future behavior of the ageing structure is acceptable in the condition that an adequate maintenance plan is implemented.

Such expertise was provided in the context of long term operation to evaluate the residual life expectancy of Liquefied Natural Gas tanks submitted to high level regulations and for which availability was a strong issue. In this particular case, the objective of this evaluation was to develop an optimized maintenance plan.

After identifying prestress loss as one of the main ageing mechanisms impacting lifetime, finite element modeling has been done to reduce uncertainties concerning residual prestress and to evaluate residual mechanical resistance. First, ageing expertise enables the determination of a realistic behavior law representing the long term deformation of concrete (creep and shrinkage). Then, finite elements simulations have provided realistic evaluations of prestress loss and residual margins of mechanical resistance in order to confirm residual life time.

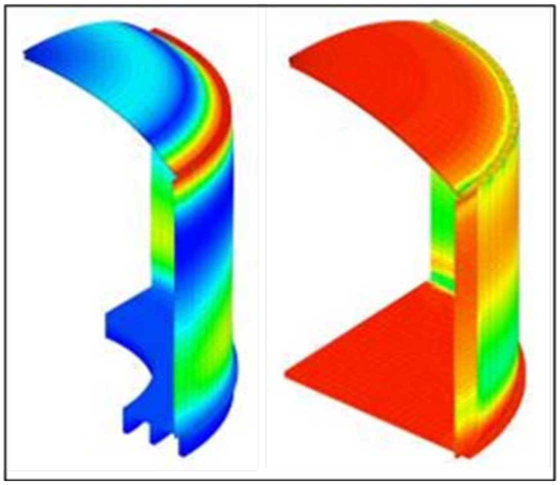

Figure 2: Impact of prestressing losses on the structure's behavior

Ageing simulation or finite elements modeling can be used to reduce uncertainties about the real condition of a structure, and to demonstrate possible life extension of the structure. They can also avoid, in some cases, important and costly corrective maintenance cost (direct maintenance cost and indirect cost: operation losses).

4. Limits of Ageing Management Programs (AMP)

Ageing Management Programs are relevant for demonstrating to the safety authority that the ageing is being well managed thanks to the identification of ageing mechanisms and the definition of preventive and corrective actions. However, some questions cannot be solved with an AMP, especially in the context of extending infrastructures' lifespan.

First, an AMP is developed to ensure plant safety, but in the context of extending lifespan, the availability also becomes an important issue. Some infrastructures are not systematically included in the scope of Ageing Management, such as turbine building or cooling towers, but their failure may impact availability. Therefore their ageing should be managed as well.

Furthermore, in many cases, AMPs define corrective actions for one structure or one group of similar structures but doesn't give a global vision of the plants' needed corrective maintenance. AMPs do not prioritize maintenance during the extended lifespan. Annual maintenance is often conditioned by budget or subjective judgment of maintenance operators. In the same way, acceptance criteria defined in AMP, against which the need for corrective action will be evaluated, are often subjective.

Finally, in order to optimize the maintenance, a strategy has to be developed to define, for example, whether it is more suitable to monitor a structure (like cooling pipes) or to replace it and avoid maintenance activities. To define this strategy, the impact of an action in terms of risk reduction or condition improvement has to be evaluated by an objective method and compared with cost in a cost/benefit analysis. Risk analysis and risk management address these two issues.

5. Risk-based Ageing Management

5.1 Risk analysis

The risk analysis methodology is based on Failure Mode Effect and Criticality Analysis (FMECA). This approach begins with a functional analysis of the system (integrating all its structural components and equipments), goes over a thorough identification and quantification of the potential failure modes, ending with a prioritization of appropriate actions.

Compared to a more traditional management method, risk based management enables the owner to take into account his own issues such as safety and costs (available budget), availability, respect of the environment, security, etc. Some risks may impact a stake more than others and a risk-based management allows to focus on the issues that really matter. Indeed, impacts assessment may highlight that non safety related civil engineering systems have a strong impact on availability. In this case, an optimized maintenance plan over the extended lifespan should aim at limiting unit shutdowns.

Risk-based management aims at guaranteeing that the owner fulfils his objectives while complying with IAEA. It enables (1) anticipation of performance discrepancies, (2) definition of a suitable action plan for risk treatment (Plan), (3) execution of this action plan (Do), (4) control of its efficiency (Check), and (5) traceability of decisions taken (Act).

5.2 Optimization of maintenance

Risk analysis enables the ranking of risks and associated actions, but prior to developing an optimized action plan, the owner has to define a maintenance strategy. This strategy is based on his operational acceptability criteria and life-cycle cost analysis, and has to answer some questions for which the following paragraphs suggest some approaches.

How to define and justify relevant actions?

The risk analysis approach enables the definition of acceptability criteria and the evaluation of risk reduction due to an action or an action plan.

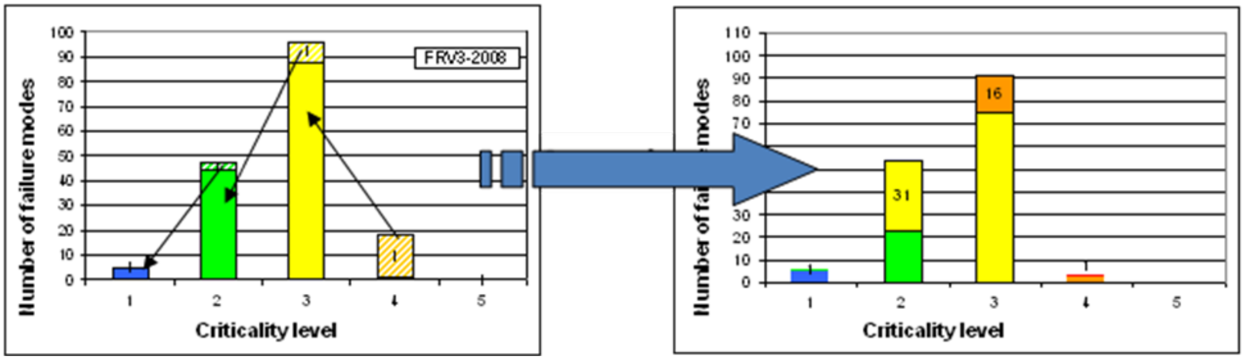

Figure 3 : Reduction of risks due to actions plan

Generally, the most critical risks (considering operational acceptability criteria) are assigned preventive treatment and/or heavy works (e.g.: replacement, repair, reinforcement). The less critical risks are mainly assigned inspections and monitoring actions. This type of action doesn't reduce the risk level but enhances control of the identified risks: ageing is monitored and actions can be taken before ageing impacts intended functions. If several actions can be possible, a life-cycle cost analysis enables the definition of an optimized action plan.

How to define and justify frequency of maintenance?

With the objective of optimizing the maintenance, risk can be quantified with an economic approach. The cost of a failure (risk cost) is compared to the maintenance cost to avoid this failure. It is then possible to compare various maintenance strategies in terms of risk and cost.
Furthermore, predictive risk assessment enables the definition of the optimum frequency of maintenance actions [3]. As the probability of failure increases with time, so does the cost of associated risks. Similarly, with more frequent corrective maintenance or replacement come higher associated maintenance cost. Thus, an optimum maintenance frequency does exist to keep the global cost as low as possible.

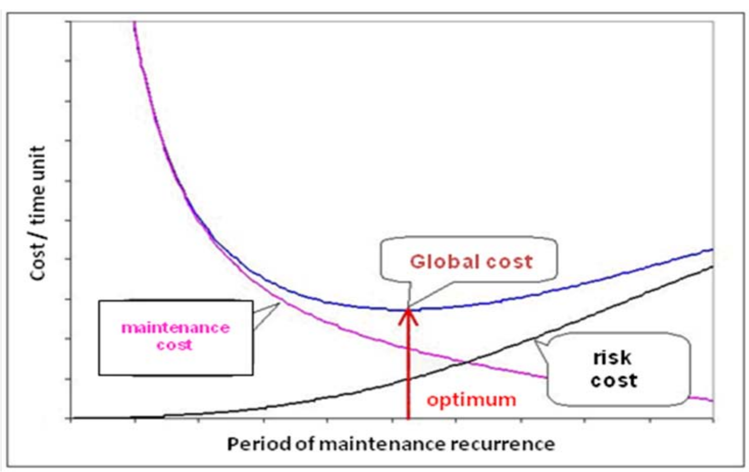

Figure 4: Global cost function of level of maintenance

5.3 Example of an Ageing Management Program based on Risk analysis

This expertise and know-how in management of infrastructure life-cycle has been applied to the ageing of cooling piping systems of French seaside nuclear power plants in order to plan and anticipate the refurbishment of infrastructure. The replacement of the piping systems can occur only every ten years during decennial visit. Owners have to demonstrate a good condition of safety can be maintained for the next ten years. Furthermore, the old buried parts were not always accessible and were sometimes exposed to complex and badly known ageing pathologies. Therefore, owner needs to define monitoring and trending methods and associated acceptability criteria to forecast the ageing of these structures, in order to minimize the production unit shutdowns and to program well in advance components replacement if necessary.

Theses cooling pipes are made of a steel core cylinder coated with internal and external concrete. An ageing mechanism's analysis shows that they may be subjected to internal corrosion by the part-flowing part-stagnant water and to external corrosion under marine atmosphere.

To evaluate the potential impact of this ageing mechanism on safety and availability, a specific finite element study was made to determine the maximum acceptance defect (acceptable size of hole due to corrosion) that does not affect mechanical resistance of piping network in operation. Then, an ageing simulation was used to assess the degradation (see Figure 1) and the minimum time required before replacement [7]. These two analyses enable the definition of objective operation criterion, to help the operator decide when maintenance is required. The operation criterion has been integrated in the preventive actions plan, and preventive and corrective actions have been indentified, like monitoring systems and replacement.

To diagnose the condition of piping system and compare it to operation criterion, a new monitoring system has been developed and installed on pipes [8]. This monitoring, associated with operation criterion and predictive simulations enables owners to postpone the replacement of pipes and to achieve an economical gain of several millions euros, without conceding on required safety level.

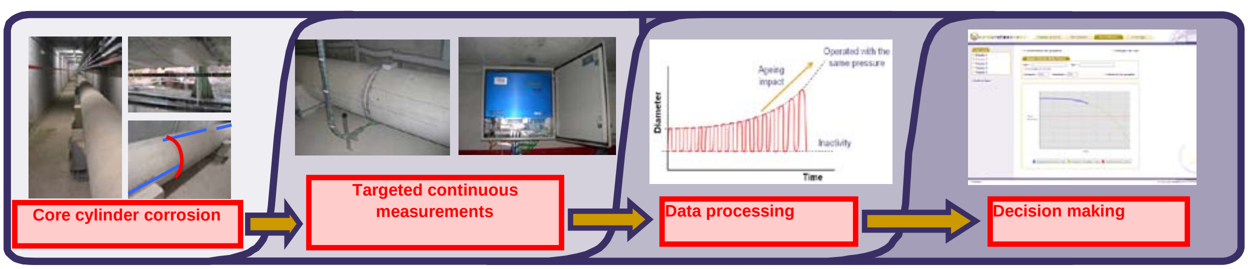

Figure 5: Decision process

This approach has proven its efficiency and now, with these tools, owners are now thinking about postponing replacement for an additional 10 years.

5.4 Action Plan Management

Nuclear Energy Producers have identified the need to improve the traceability of their decision to facilitate a required *a posteriori* justification and to make the action plan review even more efficient. To respond to their needs, a software has been developed to enable the implementation of a risk management policy. The software also enables the assignment of deadlines and the identification of the person in charge of each risk reduction measure (like corrective or preventive actions).

This collaborative tool provides, at any time, the risk profile of the infrastructures or project and the progress of risk reduction measures. In addition, it stores a log of decisions taken and facilitates internal communication.

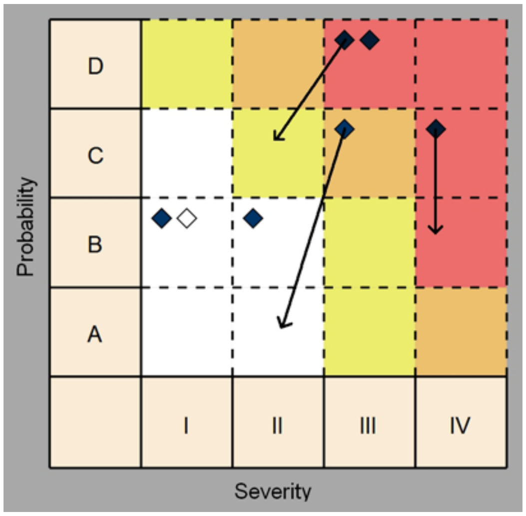

Figure 6: Evolution of risk due to reduction measures (treatment actions) with SIMEO™-ERM

6. Conclusion

Concrete structures undergo ageing, and operating conditions often change from their initial design. Predicting the variation in time of the mechanical performance of a structure thanks to a relevant condition assessment is essential in order to establish ageing management programs and optimized maintenance plans.

An Ageing Management Program can be enhanced by a risk management approach in order to take into account all of the owners issues (safety, availability …) and to justify every decision thanks to a formalized methodology and objective operation criteria.

Furthermore, this approach enables cost/benefits analyses on structure's life-cycle and then, the development of efficient maintenance strategy with, when necessary, the relevant justification of anticipated investment in preventive actions.

Finally, risk management aims to change structure management from a passive approach (corrective maintenance) to a proactive one and contributes to a potential economical gain of several million euros, without reducing the safety level.

7. References

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