Analysis, diagnosis and prognosis methods used in reliability and industrial maintenance : an overview.

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After having called again the different stakes relative to industrial maintenance and defined the different maintenance types, the paper shows the interest of preventive maintenance strategy of SSC (systems-structures-components). The objectives are to maintain or improve the safety level and to reduce unavailability and maintenance costs.

It is proved that field data analysis of failures and degradations, of inspection and health monitoring data is essential. Indeed, this analysis, in a first step, permits to express a diagnosis about the physical status of a SSC, then to forecast its future behavior.

The chapter will present some of the methods presently used in the industry. These methods are mainly based on the available knowledge from operation feedback (physical measures, historical data), from expertise and from reliability modeling or physical-probabilistic modeling. It should be added that these methods will be dealt with many R&D works .

1 The context of industrial maintenance

Objectives of maintenance are the following ones:

- to maintain or even to improve the objectives of safety – security,
- to reduce unavailability (forced or scheduled),
- to reduce costs,
- to optimize interventions (period, repair time, grouping of tasks, …) .

A particular context is the management of ageing for extending the lifetime of an unit and of its SSC. This context necessitates:

- to detect ageing,

- to assess durability,
- to define maintenance tasks to be initiated (from « do nothing » to new design),
- to perform a technical – economical analysis (an *asset management* analysis).

Finally the objective of the industry consists in optimizing preventive maintenance by analyzing failures and degradations, by making a maintenance diagnosis and by drawing up a prognosis, i.e. by predicting a remaining lifetime.

What is maintenance?

According to the European standard EN 13306 (October 2010), maintenance is the combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it, or restore it to, a state in which it can perform the required function.

It is composed of situations (measures, operation feedback, field data, long term policy…), methods and procedures, maintenance tasks (like visit, inspection, monitoring, renewal…).

Types and maintenance strategies are given in the table 1.

Note that different objectives of safety – security and industrial performances (availability, dependability, economical objectives and logistic support (localization, availability of support, grouping of maintenance tasks…)) have been defined and allocated to the various SSC of the unit.

Table 1 – Types and maintenance strategies (EN 13306, 2010).

Fundamental terms	**Definition (EN 13306, 2010)**	**Consequences**
Failure	Termination of the ability of an item to perform a required function	Loss of function , « all or nothing », reliability ageing
Corrective maintenance	Maintenance carried out after fault recognition and intended to put an item into a state in which it can perform a required function	“Run to failure”, restoration , technological methods, logistic support, reactivity

Degradation	An irreversible process in one or more characteristics of an item with either time, use or an external cause	Impairing of function, continuous phenomenon, physical ageing
Preventive maintenance	Maintenance carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning of an item	To avoid the loss of function, probabilistic concept, forecasting, prevision
Predetermined maintenance	Preventive maintenance carried out in accordance with established intervals of time or number of units of use without previous condition investigation	Assumes that the behavior of the item is well known
Condition based maintenance	Preventive maintenance based on performance and/or parameter monitoring and the subsequent actions	« Health monitoring »
Predictive maintenance	Condition based maintenance carried out following a forecast derived from the analysis and evaluation of the significant parameters of the degradation of an item	Monitoring and extrapolated prevision, also said « proactive » maintenance

As a conclusion, the objectives of the predictive maintenance are therefore:

- to secure the future function of the SSC,
- to reduce its probability of failure,
- and consequently to anticipate, on the best, the maintenance task to be performed (task which is generally heavy and costly),
- after having checked the physical behavior and the state of degradation of the SSC from measured data, field data or expertise and having set a diagnosis of the behavior and state of the SSC.

Some other terms will be used in this chapter:

- ageing mechanism: specific process that gradually changes characteristics of an SSC with time or use (EPRI, 1993),
- ageing: general process in which characteristics of an SSC gradually change with time or use (EPRI, 1993),

- anticipation or proactive assessment: identification, before they occur , of the potential events penalizing in terms of safety, availability and costs (Bouzaïene- Marle, 2005).

2 The RCM approach (Reliability Centered Maintenance)

It is a « risk informed » approach optimizing the maintenance by reliability.

Figures 1 presents the RCM approach when applied to components. We can remark that when the component is active, its reliability is calculated by means of frequential / bayesian methods mainly. When the component is passive, its reliability is determined mainly by structural reliability analysis methods (table 2).

Difficulties nevertheless can be met when applying the RCM approach. Are the future operation – environment – maintenance conditions in the image of the past? May a new ageing mechanism appear? Which is the effectiveness of the maintenance tasks? Are we able to detect an ageing process? Consequently it is absolutely essential to update periodically the preventive maintenance programs (live RCM).

Maintenance evolves since many years from a predetermined maintenance program (1980), to RCM at the end the 80's, condition based maintenance on critical equipment, life cycle management (LCM; Sliter, 2000) for extending the lifetime of a plant, asset management (2003), and now the AP-913 approach, the objectives of which is to continuously improve the reliability of SSC, to forecast their behavior, to permanently adjust their maintenance programs and to organize them (INPO, 2001; Fievre et al, 2010).

In conclusion, RCM remains a basis reference method for the optimization of maintenance.

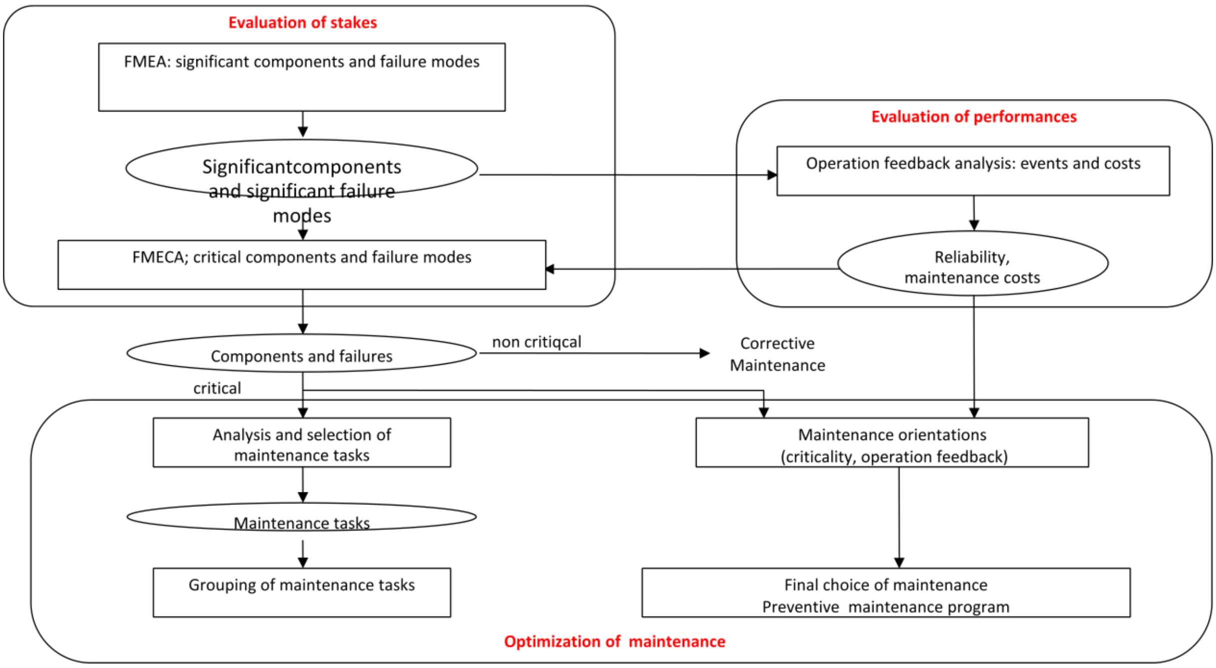

Figure 1 – The RCM approach (active components).

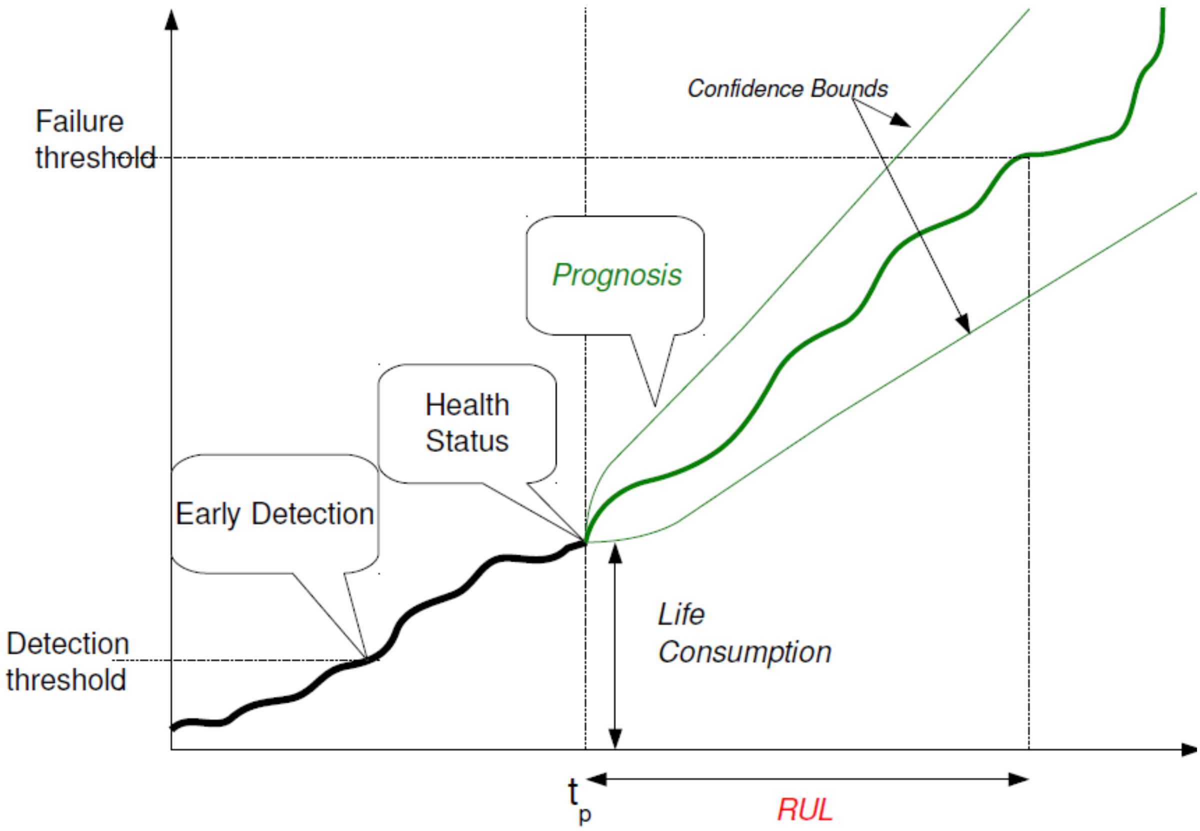

Figure 2 – Evolution of a degradation in function of operation time (Lorton et al, 2011).

Figure 2 shows the evolution of a physical parameter representing the degradation state of a component or of a structure. At the time tp of observation, the component has a usage factor (a life consumption) due to its operation before tp, the time in service. A degradation has been detected before tp but is not critical. The degradation does not impair the ability of the component to function within acceptance criteria. The health status will be the diagnosis of the physical status at the time tp. The black curve draws the evolution of the degradation or the usage factor, which have been measured during operation before tp. The green curve is a prognosis, that is the effect of future operation – environment – maintenance service conditions on the ageing of the component. When this evolution will reach the failure threshold, the component will be retired. The value RUL is the remaining life, that is the period from the stated time tp to the retirement of the component. Note that the prognosis is a prediction, consequently uncertain. It will evolve between confidence bounds.

The figure 2 shows clearly the problems met which have to be solved when establishing a diagnosis and a prognosis:

- detection of the degradation ,
- reliability and performances of sensors,
- determination of the usage factor and diagnosis (health status),
- evolution of the degradation and kinetics,
- knowledge of the future service conditions,
- effectiveness of maintenance,
- extrapolation, prediction or forecast,
- trust in expertise,
- uncertainties,
- threshold limit and acceptance criteria.

3 Failure analysis and diagnosis

Failure analysis is a systematic process of determining and documenting the mode, the mechanism, the causes and root cause of failure of a SSC.

Diagnosis is at least the result – synthesis of the failure analysis; in particular the existing maintenance strategy is examined. Diagnosis is a photography of the health status at the time of observation.

According to standard EN 13306, the definition of diagnosis is: actions taken for fault recognition, fault localization and cause identification. According to EPRI, diagnosis is the examination and the evaluation of data to determine either the condition of an SSC or the causes of the condition (EPRI, 1993).

From the diagnosis, it will be possible to predict a future behavior.

3.1 Diagnosis methods (overview not exhaustive)

Diagnosis methods depend on the knowledge we have on the SSC. This knowledge can be issued from:

- specific knowledge or design data: FMEA, FMECA, expert systems, failure trees, …

- field data: failure analysis, identification of causes, evaluation of consequences, …

- operation feedback and available expertise: influent parameters, classes of problems, actions to implement and effectiveness, …

- physical modeling: comparison between experimental observation and calculation, detection of incoherence,…

3.2 Failure / degradation analysis

Technical operation feedback for maintenance covers all the needs for dependability and safety. The maintenance model (the material – functional tree) defines the data to be collected and recorded. Note however that operation feedback gives a retrospective view, it is necessary, even for a prognosis, but it is not sufficient if a predictive behavior has to be estimated.

Figure 3 schematizes the operation feedback for maintenance.

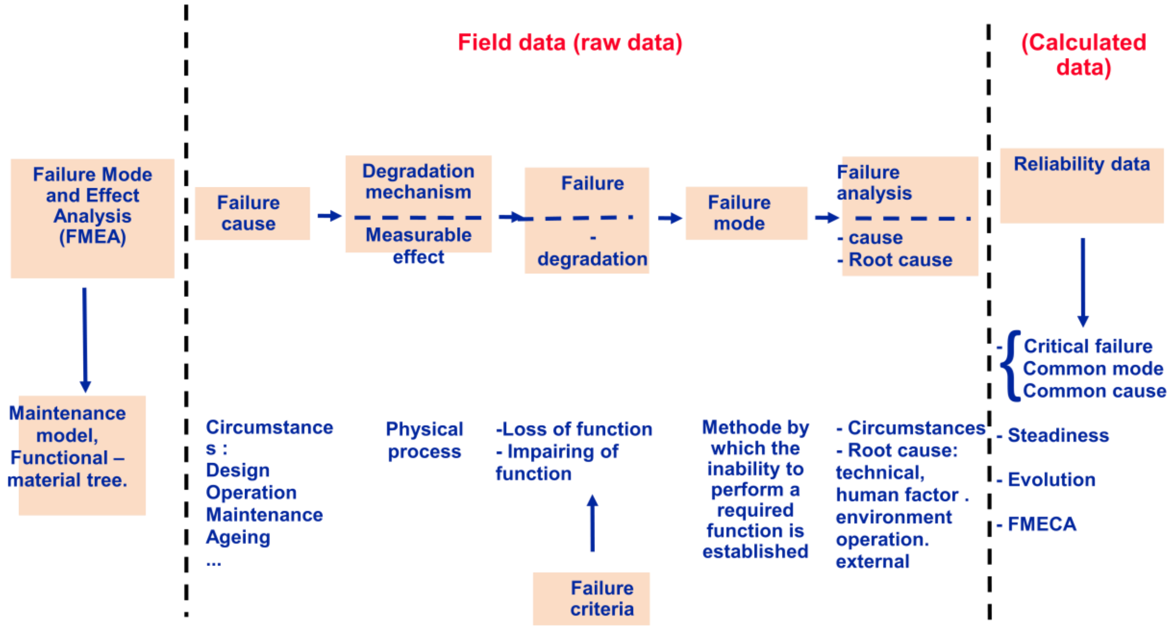

Figure 3 – Schematization of the maintenance operation feedback process.

3.3 The main methods for establishing a diagnosis

Many methods can be used:

- use of functional and technical plans,
- dependability methods like FMEA, FMECA,
- construction of tables: observed effects → causes → deduction of maintenance actions,
- diagnosis tests , comparing observed reply of a SSC to reference demands (compliance tests, remote maintenance, integrated tests),
- analysis of causes,
- expert systems: from observed facts (facts data basis), management of knowledge rules according meta- rules (if, and, or, then, arbitration, priorities) then proposition of a maintenance task,
- belief networks (see an example in the following paragraph 3.4).

3.4 Example : diagnosis from operation feedback and expertise This example concerns the function role of the seal 1 of a primary pump installed in a PWR 900MW plant (Corset, 2003, 2006).

The seal 1 is a mechanical component; it separates the rotor from the static subcomponents. Its function is to secure the dynamic tightness between the fluid (contained in the primary pump) and the external environment. It is a hydrostatic type seal with controlled leak. It undergoes pressures up to 15.5MPa. The pressure downstream is between 0.2 – 0.3 MPa.

The diagnostic objectives are the following :

- a better understanding of the ageing process (modeling of the lifetime, modeling interaction between different variables, estimation of the probability of failure, detection of the most influent variables),

- a better risk and costs management (identification of the adapted maintenance options, quantification of the impact of these maintenance options, postponement or suppression of ageing),

- a help for optimization of maintenance (sensitivity analysis, data analysis, help for diagnosis, help for decision making).

A belief network has been built. This tool has been chosen because it makes possible reasoning with uncertainties. Variables have been grouped according to the figure 4.

Operation parameters ↘

Age of components → Diseases → Observed parameters → State of seal 1

Influent parameters ↗

Figure 4 – Grouping of variables by a hierarchical way.

Three types of variables (figure 5) are considered:

- an output variable, the status of the seal 1, E, to be explained,

- independent input variables, the modalities of which being determined from operation feedback or expertise,

- intermediate variables, the links between these variables being conditional probabilities deduced from operation feedback or expertise.

The belief network is presented on the figure 5. Note that this network synthesizes the qualitative and quantitative knowledge about the behavior of the component.

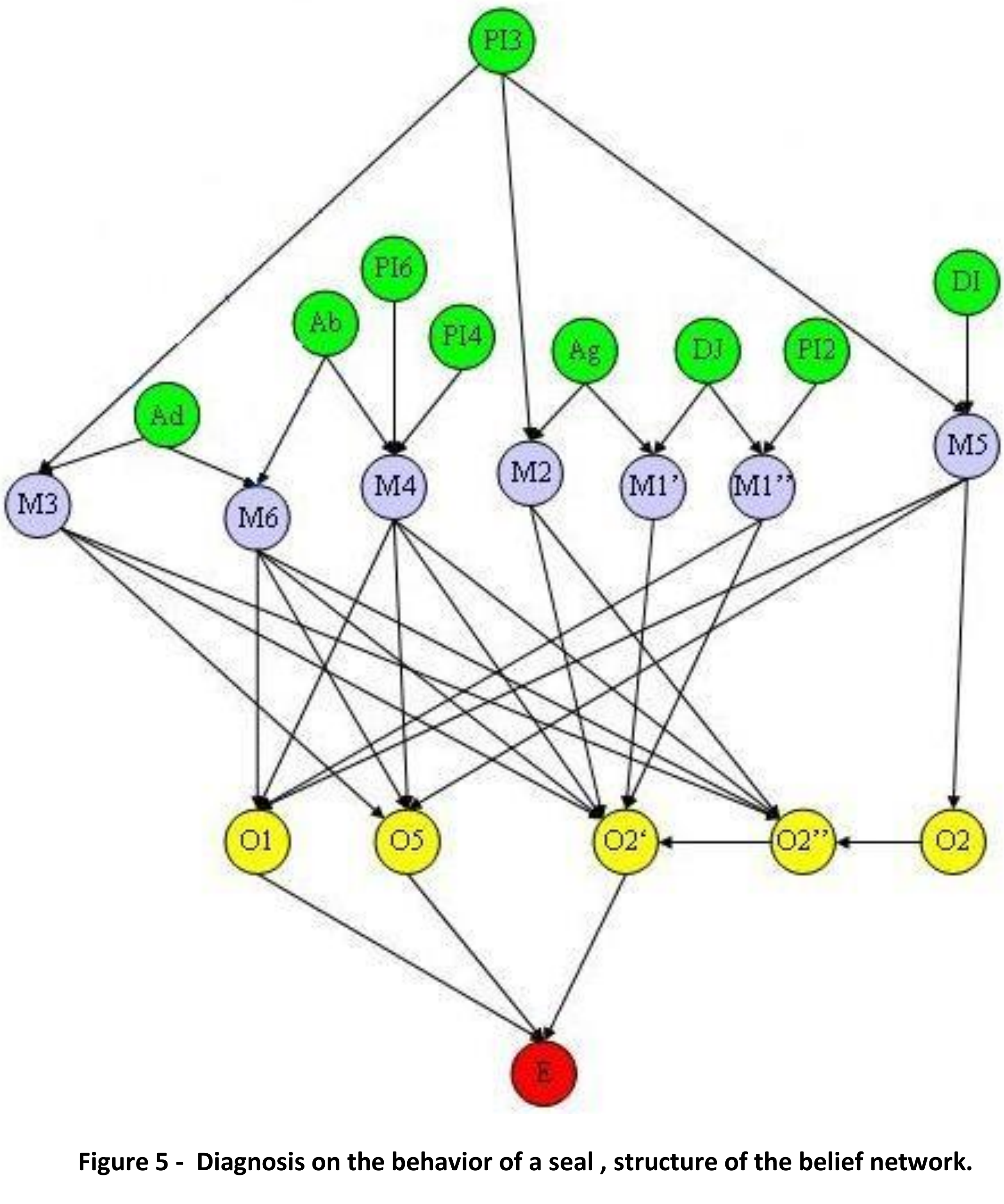

Figure 5 - Diagnosis on the behavior of a seal , structure of the belief network.

(Ad, Ab, Ag: age of subcomponents; DI, DJ: influent parameters; PI2 to PI6: operation parameters; variables M: diseases; variables O: observed variables; E is the status of the seal 1)

Corrective or preventive maintenance actions can be imagined in the purpose of improving the behavior of the seal. These actions are represented by a fourth type of variables, the action variables, on the figure 6 (blue circles).

They have a new influence on some input and intermediate variables of the belief network, modifying thus the input probabilities and the conditional probabilities.

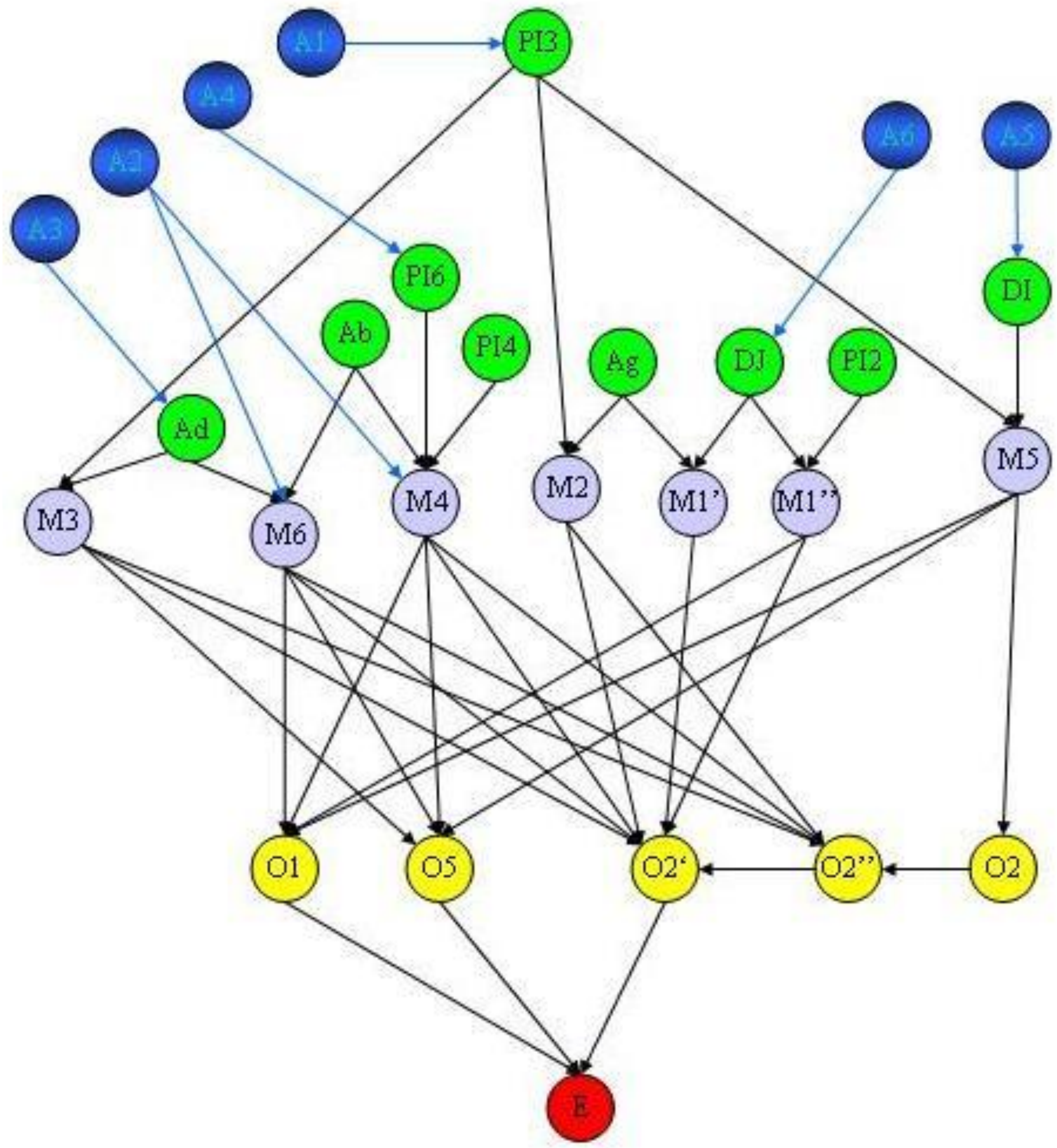

Figure 6- - Diagnosis on the behavior of a seal , impact of the action variables.

(variables A1 to A6: action variables(maintenance tasks))

3.5 Conclusion

Diagnosis is a photography of the physical state of an SSC at an observation time. It is part of a sourcebook or of a check-up of the SSC. Limits of diagnosis are mainly due to a not validated operation feedback, incomplete data, ageing or evolution of service conditions, organizations or regulatory guides.

4 Prognosis

4.1 Generalities

A prognosis consists in:

- identifying (anticipating) potentially penalizing situations (here, failures) in terms of safety and profitability,
- estimating the remaining lifetime,
- defining actions to implement (here predictive maintenance actions).

Prognosis will depend on available information of the past (operation feedback, results of inspections…), of the present (the diagnosis, the health assessment of the SSC) and of the future (the future service conditions of the SSC).

The maintenance decision in fine will depend on the predicted behavior of the SSC and of its uncertainties and on economical criteria of asset management. It can be pointed out that reliability is confirmed as the most important factor in the maintenance decision.

4.2 A quantitative indicator : the mean residual life (or remaining life).

It can be calculated by the following formula (Lannoy, Procaccia, 2006):

$$m_m(t) = \frac{\int_t^{\infty} \int_a^b R(u, \theta) . \Pi(\theta) \, d\theta \, du}{\int_a^b R(t, \theta) . \Pi(\theta) \, d\theta} = \frac{\int_t^{\infty} R_m(u) \, du}{R_m(t)}$$

where t is the observation time, R is the reliability law depending on a parameter vector Θ, Π is the probability density function of Θ, a and b the boundaries of the domain.

This indicator is very difficult to calculate because it needs to know the future service conditions, the most precisely possible. It is also necessary to know the reliability (or ageing) law versus operation time. The resource of expertise is needed for estimating the reliability parameters and calculating this predicted reliability. Uncertainties have to be assessed.

4.3 Prognosis methods (overview not exhaustive)

Prognosis methods used will depend on the information available. This information and knowledge can come from:

- operation feedback: methods used can be CBR (Case Based Reasoning), detection methods (graphical or bayesian), reliability methods in a very censored context, methods determining the effectiveness of preventive maintenance (paragraphs 4.4 and 4.5),

- inspection data, permitting the determination of a degradation law, by regression, logistic regression , gamma process, … (paragraph 4.6),

- health monitoring data, observations or measurements of condition or functional indicators that verify that a SSC currently can function within acceptance criteria: methods like Cox model, data mining (clustering, principal component analysis, decision tree, …), estimation of physical state by extrapolating the evolution of a characteristic parameter, comparison monitoring / reliability, can be used (paragraph 4.7),

- operation feedback and expertise: methods of proactive assessment (like AVISE, PMDA-PIRT, see paragraph 4.9),

- physical modeling using accounting of situations and events, Miner criterion (in the case of thermal fatigue), TLAA (Time Limited Ageing Analysis (Lannoy, Procaccia, 2005), simulation (paragraph 4.8),

- simulations of probabilistic behavior of SSC: Petri nets, PDMP (Piecewise Deterministic Markov Process, (Lorton et al, 2010)), forecast studies using belief networks, …

4.4 Some methods using operation feedback

Most popular and easy to use methods are the following ones.

CBR uses operation feedback for solving a problem. Analogous cases are retrieved in a knowledge data basis engendering a prognosis and a solution ; after validation the new case becomes a knowledge (learning from experience) (Leake, 1996).

Graphical methods are very practical because user friendly. One of the most practical and easy to use is certainly the TTT method (Total Time on Test) (Klefsjö, 1982). It needs to class the failures and the censored observations of a SSC, repairable or not. The concavity of the curve obtained permits to classify the data observed in steadiness or decreasing failure rate or increasing failure rate, which can be confirmed by a Barlow-Proshan test.

Bayesian methods have been used by (Clarotti et al, 2004) for detecting an ageing detection.

4.5 Reliability methods, treatment of failures and degradations

Operation feedback analysis consists of several steps:

- selection of a sample on criteria,

- qualitative failure and degradation analysis and validation at the sense of relevance of data,

- treatment, data mining, reliability analysis,

- interpretation,

- analysis of specific reports concerning safety, maintenance, human factor , materials.

A reliability law is calculated. Table 2 gives the main methods used depending on the type of component and the size of operation feedback. As an operational reliability law is calculated, frequential methods are the most often used.

Operation feedback is essential, it permits a reliability monitoring of the SSC for managing degradations, it traduces the usage factor. Preventive maintenance disturbs the real behavior of the SSC. Complementary information (like future service conditions, maintenance programs, reliability tests, physical calculations, expertise (of designers, maintenance engineers), data simulation, data handbooks, analogous feedback, technology survey) is necessary. The periodical output of a reliability data handbook (like the EIReDA handbook for the nuclear industry or the OREDA book for the petroleum industry) is certainly a very good quantitative indicator if published every 2 to 5 years. The handbook traduces the operation – maintenance quality of the industry, transparency in relation to safety. The reliability handbook and its updating are health monitoring tools. Data from handbooks have to be adapted to the design and to the service conditions very often different of the ones of their assessment.

Table 2 – Main reliability methods used for the determination of an operational reliability law.

Operation data (failures, operation times, maintenance history)			
Component	No data	Some failure data	More than 20 failure data
Active	Khi-2 method Method of the integrated likelihood Min-max method of likelihood	Bayesian methods Frequential methods with simulation of incomplete data	Frequential methods (maximum likelihood, …) (or bayesian)
Standby active	Khi-2 method Method of the integrated likelihood Min-max method of likelihood	Bayesian methods	Frequential methods (maximum likelihood, …) (or bayesian)
Passive	Stress-resistance methods Structural reliability	Structural reliability analysis or bayesian methods	Frequential methods (maximum likelihood, …) (or bayesian)

The references (Bacha et al, 1998), (Lemaire, 2005), (Lannoy, Procaccia, 2006), (Gerville-Reache et al, 2011), (Ferton et al, 2011) can be consulted for the proposition of different methods of a predictive or an operational reliability law.

4.6 Inspection data

Generally degradation effects are measured: a depth or a length of a crack, the loss of material, …, the ageing mechanism being known. Difficulties can be met when measuring: which are the performances of the sensors? Which is the probability of detecting a crack? Which is the rate of inspection (complete or more often partial)? Moreover a number of censored data have to be managed. Then from the inspection data a reliability law and its kinetics is searched. The degradation level is compared to a threshold limit which is a criterion for acceptance.

Physical laws concerned are mainly fatigue (depending on amplitude and number of stress cycles), corrosion (service time and environmental conditions), creep (temperature, stress level and service time), wear (depending on loads and length of sliding).

The degradation law is determined using physical representation or regression techniques or stochastic modeling (for instance the gamma process or the Wiener process).

4.7 Prognosis from health monitoring

It is necessary to find a correlation between the state of degradation of the SSC and several parameters which can be measured. A great number of data is generally obtained. Data analysis using classical data analysis techniques or neurons nets are applied for classifying failure families, classes of problems, state of degradation. Cox model (proportional hazards modeling) is currently used expressing the hazard function h (t, Z) versus age t and Z, the vector of explicative co-variables, B being the vector of influence factors, generally estimated by the maximum likelihood method:

$$h(t, Z) = h_0(t).\ \exp(- B . Z).$$

Table 3 compares the reliability approach (paragraph 4.5) to the monitoring approach.

Table 3 – Comparison reliability approach / health monitoring

	Reliability approach	**Health monitoring**
Investment	Weak	Moderated
Approach	Mathematical approach	Degradation law, often unknown
Input data	Failure data (loss of function) and maintenance data, expertise	Measured effects, physical tests
Samples	Small samples	Important samples leading to analysis difficulties
Characteristics	Uncertainties, simulations	Short term predictions

4.8 Prognosis from physical assessment

It corresponds mainly to the domain of TLAA (Time Limited Ageing Analysis). For example, in the case of thermal fatigue, a first step is to model the temperature field and the stress field by finite element methods. The events (the situations) are counted and classified in classes. The Miner criterion is applied. A usage factor and a remaining life can be predicted. The impact of future conditions services and of material properties can be measured.

4.9 Prognosis from operation feedback and expertise: forecast methods

These methods have been developed by the nuclear industry since several years. The AVISE methodology (Bouzaïene- Marle, 2005) and the PMDA-PIRT methodology (US NRC, 2007) are some of the most popular methods.

These two methods aim to evaluate the potential impact of ageing on the SSC. Operational data and expert judgments are used in structured approaches to identify and evaluate ageing effects. The goal is to proactively address potential future degradation to avoid failures and to maintain integrity and safety.

4.9.1 AVISE methodology

AVISE methodology allows to evaluate the physical SSC state, to identify ageing effects and to find relevant solutions to avoid or postpone ageing. It consists in four phases: definition of the context and objectives, identification and gathering of the information needed for anticipation, surveying of experts, and synthesizing and exploiting results.

Functional analysis, design documents and, most particularly, Reliability Centered Maintenance (RCM) studies can inform about the potential failures of a piece of equipment. Feedback can provide information on failures actually observed in equipment. However, if the environmental, operating or maintenance conditions or the duration of operation of the equipment change in relation to those considered at the time of design, only expert judgment is capable of predicting the impact of the changes. Drawing on existing data, the expert can identify the potential failures, which might occur subsequent to these changes. He is therefore an important player in the anticipation process.

Information needed to ageing anticipation is listed below :

- **Functional data: f**unctional data includes the global equipment functions and the function-equipment breakdown, which breaks equipment down into groups of components performing the same function.
- **Design data: t**his data includes all elements relative to the design of the component. It groups the equipment components, the technical diagrams, the geometric dimensions of the different components, the materials used, the manufacturing procedures and the related costs.

- **Data on materials: t**his data is related to the different materials used to make up the component. It groups the chemical and mechanical characteristics of the materials, their properties and a description of any welds (if appropriate).
- **Operating parameters: o**perating parameters include the temperatures, pressures, flow rates and chemical environments of the component in question.
- **External environment data: i**t gives information about the ambient environment in which the equipment operates, and its interactions with other components.
- **Operating data: t**his data is related to the different operating modes for the equipment, the number of cycles and the number of hours of operation.
- **Maintenance data:** maintenance data is in relation to preventive maintenance programs, but also includes the various costs of maintenance, data on obsolescence, regulations and reports on safety, reliability and aging.
- **Feedback data:** it includes traditional feedback from the company, feedback on ‘‘analogous’’ equipment and from plants outside France, and reports on reviews of the state of the art.

During the survey step, several tools and elicitation methods are used to:

- identify potential degradation mechanisms,
- study the relevance of these mechanisms,
- analyze and rank the relevant mechanisms,
- analyze and rank potential failures (kinetics, seriousness, effects of aging, consequences)
- and finally identify potential avoidance solutions and examine the relevance of these solutions in terms of efficiency and cost.

A creativity approach, structured elicitation techniques and Bayesian networks are examples of tools used in the AVISE methodology.

A creativity approach, based on stimulation of expert knowledge is used to identify potential degradation mechanisms. as exchange among the experts can stimulate the emergence of ideas, collective questioning appeared to be best suited to this step. A structured method was defined to enable stimulating creative experts thinking and helping them to make optimum use of the information gathered and their own knowledge.

Starting with a global list of degradation mechanisms and failure modes, the method developed provides for several successive filters. These filters oblige the experts to go over the global list and eliminate irrelevant mechanisms in accordance with a predetermined logic. To complete the global list and ensure that the final list is exhaustive, the experts are asked to do a preliminary exercise: each must note down the potential degradation mechanisms and failure modes for the SSC. The new mechanisms are integrated in the global list before the group survey. Figure 8 presents theses filters applied to the pressurizer, a nuclear power plant component (see figure 7).

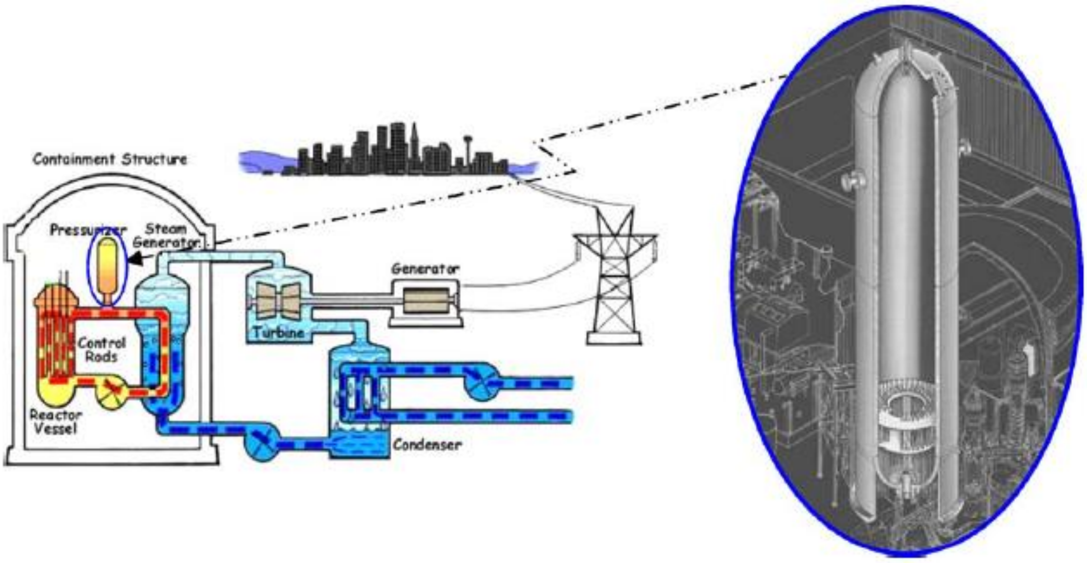

Figure 7 - Pressurizer in a nuclear plant.

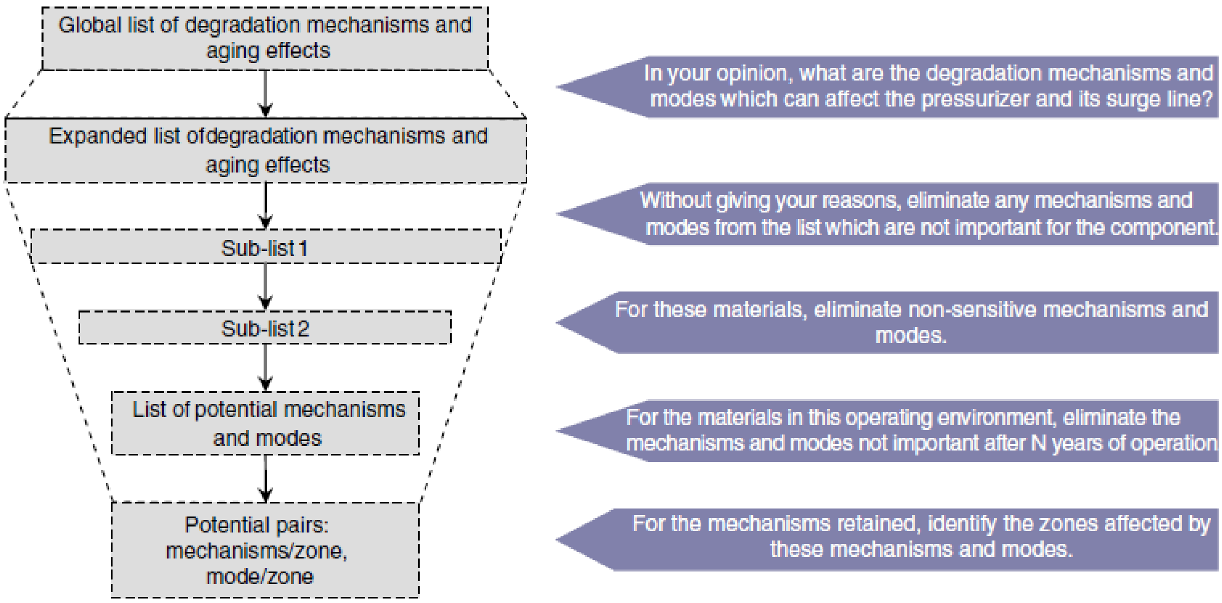

Figure 8- Survey of experts to identify potential degradation mechanisms.

An example of a belief network to study the relevance of thermal fatigue in the pressurizer, is presented in figure 9.

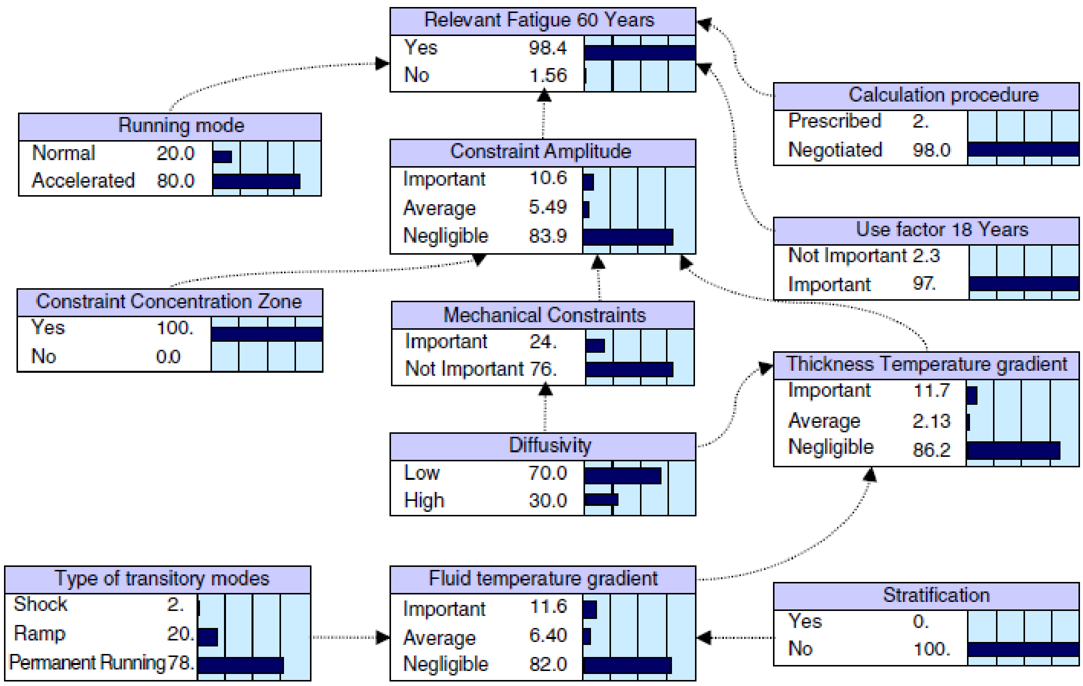

Figure 9- An example of a belief network used in AVISE methodology to study the relevance of thermal fatigue in the pressurizer.

Developed and applied in 2005 for a passive component at EDF (France), AVISE methodology was adapted to active component in 2010 (Cagnac & al, 2010). It was also applied in 2011 for prioritization of components important for safety and sensitive to ageing for the TRIGA reactor in Romania (Nitoi & al, 2011).

4.9.2 PMDA-PIRT methodology

The PMDA-PIRT methodology was developed by the Nuclear Regulatory Commission's (NRC's) in the framework of the Proactive Materials Degradation Assessment program (US NRC, 2007). The main objective was to identify materials and components where future degradation may occur in nuclear reactors. The approach was to use a structured elicitation drawing on the knowledge of a panel of experts and the use of a Phenomena Identification and Ranking Table (PIRT) process.

A two-step approach was used for this methodology. The first step was to identify susceptible materials and locations where degradation can reasonably be expected in the future. Probabilities of failure and associated uncertainties for important components were also be estimated. The second step was to cooperatively develop and implement an international research program for the components and degradation of interest. This research program addresses materials and degradation mechanisms, mitigation, repair and replacement, and nondestructive evaluation.

The first step consists on identifying materials and locations where degradation can reasonably be expected in the future.

The first portion is to identify components that have already experienced, or are likely to experience, degradation using currently available information from different sources such as the Generic Aging Lessons Learned (GALL) report and a database on plant events.

The second portion of the identification step involves identifying components that may be susceptible to future degradation using a structured approach that takes into account the specific component material in its operating environment and its associated stressors. For this work, the NRC has assembled a panel of international experts in materials engineering, corrosion science, and reactor systems to systematically develop a list of components susceptible to future degradation. This process is based on the methodology used to develop Phenomena Identification and Ranking Table(s) (PIRT).

370 sub-groups of 2200 components and associated degradation phenomena are then identified. Components were placed in the same sub-group if they were in the same sub-system, were of the same or similar material type and product form (e.g. cast stainless steel, wrought stainless steel, carbon steel, etc.), and that are exposed to similar operating environments and other stressors, and would therefore be susceptible to the same degradation mechanisms.

Once the sub-groups and associated degradation phenomena were identified, the expert panel members individually assigned numerical values to each of three parameters for each degradation phenomenon identified. These three parameters are Susceptibility Factor, Confidence Level, and Knowledge Level and the ratings for these parameters are defined in Table 4.

Table 4- Scoring and associated definitions for parameters rated by individual expert panel members.

Susceptibility Factor – Can significant material degradation develop given plausible conditions?
• Blank = not evaluated by the expert • 0 = not considered to be susceptible to the particular degradation mechanism by the expert • 1 = conceptual basis for concern from data, or potential problems under unusual operating conditions, etc. • 2 = strong basis for concern or known but limited plant problem • 3 = demonstrated, compelling problem or multiple plant observations
Confidence Level – Personal confidence in experts' judgment of susceptibility
• 1 = low confidence, little known about phenomenon • 2 = moderate confidence • 3 = high confidence, compelling evidence, existing problems
Knowledge Level – Extent to which the relevant dependencies have been quantified
• 1 = poor understanding, little and/or low-confidence data • 2 = some reasonable basis to know dependencies qualitatively or semi-quantitatively from data or extrapolation in similar "systems" • 3 = extensive, consistent data covering all dependencies relevant to the component, perhaps with models – should provide clear insights into mitigation or management of problem

1100 assessments on degradation mechanisms concerning the sub-groups of components were performed. They are based on experts knowledge and experience, consideration of past experience in addition to degradation that has not yet occurred due to a) long incubation periods, b) new or different degradation mechanisms, c) time dependent phenomena such as concentration of aggressive chemical species, fatigue, and thermal aging, d) plant operating history and more recent changes in operational parameters and environments such as power up-rates, temperature, stress, and water chemistry, and e) other considerations.

In addition, probabilities of failure and associated uncertainty estimates for the components were determined for use in PRAs.

The review of existing information to identify components that have experienced and are likely to experience degradation, evaluation of nondestructive examination and leak monitoring techniques and requirements for these components, and recommendations for improvements where necessary has been documented in a draft report (US NRC, 2007).

The second step consists on using the results from the PMDA PIRT exercise, among other inputs in the framework of an international cooperative group who develop, sponsor, and implement a research program, and share research results that develop the technical basis for industry and regulatory bodies to proactively implement effective approaches to materials degradation management.

5 Conclusions

Prognosis necessitates a preliminary diagnosis. This diagnosis is established from available knowledge and essentially from operation feedback (consequently very strategic for companies).

Many methods can be found for predicting the future behavior of SSC, in particular anticipation methods and reliability methods.

The diagnosis quality depends on the knowledge available. Any information, whatever it can be, even if sparse or incomplete, may impact the diagnosis quality and has to be taken into account because it improves knowledge and reduces uncertainty.

SSC are very heterogeneous. A diagnosis-prognosis approach has to be prepared for every SSC, when monitoring and analyzing its behavior. A single approach, able to be applied to every SSC of a complex system, seems difficult even illusive. Physical models are likely to be the more efficient for reducing uncertainty. They are however difficult to obtain in real service conditions.

The maintenance decision depends very often on economical criteria (expected benefits) or regulation rules.

The diagnosis- prognosis is still at the level of R&D, even if application in different industrial sectors (airspace, railway, nuclear) can be found.

The main R&D perspectives cover the following problems: detection of ageing, performances of sensors, determination of a degradation law, assessment methods of the remaining lifetime, efficiency of maintenance, impact of the human factor on this efficiency, thresholds limits, acceptable reliability.

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