

**Abstracts for ESReDA 31st seminar on Ageing**

*Draft order of presentations (Only first author given here)*

Session 1. General considerations on ageing of Units and Systems.  
Beukenkamp, Massé, Rodionov, Slugen

Session 2. Identification and detection of ageing.  
Sellali, Pervukhina, Rogante, Saleem

Session 3. Evaluation of ageing of Systems and Structures.  
Cano, Guyot, Kudsys, Yalamas

Session 4. Evaluation of ageing of Components  
Bris, Gabrielsson, Kerdy, Ziani, Cognard

Session 5. Ageing PSA.  
Blombach, Burgazzi, Cebin, Rodionov

Session 6. Ageing management and efficiency of maintenance  
Brezina, Deloux, Kupca

## **Ageing: a challenge to transport systems**

Willem Beukenkamp AVV/Transport Centre

Rob Methorst AVV/Transport Centre

In most countries – The Netherlands being no exception – policy regarding the safety of transportation systems is determined by solving urgent problems first. Hidden long-term threats such as ageing of transport systems and their users are therefore not very high on the political agenda. Nevertheless, these threats are real and increasing in importance, as recent research by Methorst has shown. In 2030 around 22% of the Dutch population (3.7 mln people) will be older than 65 years. As a direct result, 1.6 mln people, most of them elderly, will have limited mobility. These limitations induce additional quality demands to transport systems. At the same time, other developments in these systems introduce increased threats to elderly people, such as a continuing growth in car mobility (also by elderly people at increasing higher ages). More cars, more lorries, more vulnerable people: crossing the street may become very difficult indeed.

The ageing problem is not limited to human beings. Technology shows this problem as well. Hardware becomes more and more durable. ICT control systems however show a very different trend, whereby the lifespan of generations decreases rapidly. Ageing of these systems creates problems in their long-term operation. It makes it more complex to maintain, increasing their vulnerability as Beukenkamp has shown earlier. Additionally it makes it more complex to ascertain that the requirements of their users keep on fitting. Elderly people have other operational requirements than younger people.

AVV has developed the Pizza-model to explain the behaviour of transport systems in a more dynamic way. This paper will explain the consequences of the ageing processes regarding transportation systems using this Pizza-model. It will be shown that the problem of ageing affects every part of a transport system, using four perspectives: the transport system users' perspective, the transportation perspective, the physical environment perspective and the social environment perspective.

"

"

## Ageing topics in aeronautics

Jean-Remy Masse

System, Structure and Component (SSC) ageing is rather related to slow degradation than sudden changes. Ageing follow-up allows to optimise refurbishing periods. This is illustrated with two examples related to aircraft turbofan engine ageing: Overall engine ageing and main fuel pump ageing.

Two kinds of ageing models are considered in the examples from aeronautics:

- Probability density function of the time to event
- Ageing effect relevant parameter curve until threshold.

The first kind of approach, natural to statisticians and reliability engineers, is based on estimation of probability density function. It allows to optimise constant “Time between overhaul” in a preventive maintenance perspective for in-service fleet.

The second kind of approach, natural to engineers, is based on the physics of the ageing effects. Relevant parameters related to efficiency are appropriate for trend monitoring. It allows predictive ‘on condition’ adaptive time between overhaul in a predictive maintenance perspective. An analytic knowledge of the trending curve is useful.

Furthermore, the second kind of approach may be extended to parameterisation with environment conditions and flight profiles. This is made possible through the cooperation of engineers and statisticians. It allows to forecast the distributions of maintenance operations during invoice periods of future fleet of airframe under development.

In the future it would be good to find an analytical frame connecting a time to event distribution function with the physical curve trending.

"

"

"

## **Aging PSA as a tool for evaluation of impact of aging and maintenance of SSC to the overall plant safety**

*A Rodionov (JRC PETTEN/NL),*

*C. Kirchsteiger (JRC PETTEN/NL)*

The paper will present a brief summary of EC JRC Aging PSA network activities and futures actions planned, as well as some results obtained from feasibility studies and benchmark exercises. Specific emphasis will be done on the task of reliability data and operating experience analysis and interpretation of the results.

The Network on Incorporating Ageing Effects into Probabilistic Safety Assessment (Aging PSA) is under development within the framework of the JRC FP-6 institutional Project "Analysis and Management of Nuclear Accidents".

The Aging PSA state of the arts "living report" ([www.energyrisks.jrc.nl/APSA](http://www.energyrisks.jrc.nl/APSA) ) provides several examples of feasibility studies carried out by the network participants.

The following case studies are performed or under development now :

- Demonstration of statistical approaches to identify the component's aging by operational data analysis,
- Incorporation of Ageing and Maintenance Effects into System Reliability Models,
- Investigation of component age dependent reliability models : representativeness, uncertainties and predictive extrapolations.

Some results of these activities will be presented and discussed.

The main outputs from the network activities (2004-2006) could be summarized as follows ;

- Aging PSA could be used as a complementary to the deterministic approach, for evaluation of SSC aging impacts to the overall plant safety,
- related areas of applications are the Periodical Safety Review, Aging Management, Maintenance Optimization and Lifetime Extension activities,
- incorporation of aging effects into the PSA model require important resources and time allocations,
- methods and approaches of Aging PSA are not well developed for the moment and need additional R&D.

## **Contribution to preservation and management of nuclear knowledge on WWER reactor pressure vessels**

Luigi Debarberis, EC JRC Institute of Energy, Petten, Netherlands

Milan Brumovsky, Nuclear Research Institute Rez plc, Rez, Czech Republic

Vladimir Slugen, Slovak University of Technology, Bratislava, Slovakia

Marek Miklos, Slovak University of Technology, Bratislava, Slovakia

Andrej Zeman, JRC Institute of Energy, Petten, Netherlands

Nuclear knowledge preservation activities are ongoing in the EC-JRC Institute of Energy with the intention to collect all available information about reactor pressure vessels of WWER type reactors as well as to analyze and summarize the most important items and issues. This activity is in line of the European Community FP6 projects PERFECT (Prediction of irradiation damage effects on reactor components) and mainly COVERS (Coordinated action on WWER safety) in which all WWER operating countries also take part. Actually, the electronic database was created and is accessible for young or expired researchers in this area. The access is recommended via ODIN (Online Data and Information Network) <https://odin.jrc.nl/doma>. After registration you can enter the WWER DoMa-db: "Database of references for knowledge management and Preservation on WWER reactor pressure vessel". For the access to confidential information you have to ask an indicated administrator.

The nuclear knowledge management is realized not only via database creation or education process during undergraduate (Bc.), graduate (MSc.) and postgraduate (PhD.) study but also via specialised training courses in a frame of continuous education system, research activities and projects, workshops seminars, ect. For illustration of the actual status and possibilities, the Slovak nuclear knowledge model is used. Unfortunately, decrease of number of employees in nuclear and "human ageing" of experts seems to be a serious problem not only on world but also in Slovakia.

## **Neuro-Fuzzy techniques for Diagnosing in Power Transformer**

Brahim SELLALI El, IMdR-SDF  
El-Hadi REBAA University of Val de Marne Paris  
Najet AOUCHAR Schlemberger

**Abstract:** The paper focuses on the implementation of hybrid neuro-fuzzy techniques, which cooperate in solving the specially problem in fault detection applications. The objective of this paper is to detect faults to an electrical power transformer, with emphasis on faults occurred in the dielectric part of the ageing equipment. A neuro-fuzzy based learning and adaptation of Pedrycz fuzzy models is used for decision-making aid, with a Neuro-Fuzzy classifier for Mamdani models is used. The paper is concerned on how to obtain an interpretable fault classifier as well as interpretable models for analysis and faults diagnosis. We complete our work by an application on a power transformer.

## Method to determine functioning deviations for complex technical objects

Prof. Dr. Elena Pervukhina Sevastopol National Technical University

Departures from a normal functioning of complex technical objects which are results of changing of their mechanical and physical characteristics due to ageing are usually discovered by plotting and viewing data on a variety of special control charts. The method has serious disadvantages. The conclusions are dependent on the operators' knowledge and it is very difficult to identify damages until then parameter values run up to their limits. Moreover kept information is not fully used during the diagnostics.

The method to determine functioning deviations of complex technical objects based on the Kullback-Leibler information measure is proposed. Method does not need additional measurement means. It based on the known statement: at nominal functioning regime parameters deviations are random and correlations between parameters are stable. At the damages the character of parameter deviations is not random and relations between parameters are broken. This fact permits to forecast the breakdown state of complex technical objects.

The solution is formed by determination of the main informative parameters of the objects, showing up the correlation and functional dependences and establishment of invariant consequences of measurement changes of different parameters.

The example of investigation of quantitative and qualitative dependences between parameters of the technical objects is shown.

### References:

1. Bohonsky A., Pervukhina E. *The Estimation of Resource of Mobile Railway Elements Based on Spectrum of Own Frequencies* // Proceedings of IX International Conference "The Problems of Mechanics of Railway Transport", Dnipropetrovs'k, pp. 196-197, 1996 (in Russian).
2. Pervukhina E. *The Methodology of Machines' Tests Based on Informative Analysis of Diagnostic Models* // Automation and Modern Technologies, Moscow, N. 12, pp. 31-33, 1997 (in Russian).

## **Nanostructure characterisation by SANS for investigation on ageing**

M. Rogante Rogante Engineering Office

V. T. Lebedev Petersburg Nuclear Physics Institute

Ageing and creep resistance, as other mechanical properties, are decisively dependent on nanostructure (e. g., pores, precipitates and dislocations groups) formed in metals. A not uniform material degradation, in fact, directs to remarkably rapid development of cracks and critical reduction of the metal component's lifetime. The operating temperature of mechanical components, moreover, is sometimes very close or, in certain cases, can exceed the ageing temperature. The problem of long-term materials exploitation under extreme thermal and mechanical stresses requires the application of innovative methods which facilitate to examine the material state and to be the precursors of possible material's ageing and fracture.

The most successful experimental approach, in this field, is the Small Angle Neutron Scattering (SANS), possessing considerable advantages as compared to the traditional fractography and the material testing methods.

In this paper, some examples are reported showing the adoption of the SANS method in order to investigate on ageing, and some theoretical bases are reported. The same method can give new possibilities to investigate the nanoscopic features of destruction mechanisms, yielding rich information on the processes in the whole considered volume. Finally, SANS allows, in some type of materials, to characterise very small precipitates at early ageing time while they are not detected.

## **Ageing - Can we delay the process?**

Amair Saleem, Douglas Forbes, Connie Lum

Ageing is a progressive and ongoing process. Very often, it depends on a great number of influencing co-variables: period of operation, loads, physical properties of materials and operating conditions, to mention only those that generally play a preponderant role. Ageing may also be triggered by other technological, or even social or economic factors: performance inferior to that of new and more modern equipment; concept, design or materials surpassed by new technologies; incompatibility or obsolescence of the control and command system and software; lack of spare parts; profitability limit reached; more stringent regulations; stricter safety margins and evolution in the operating profile of installations and in environmental regulations. Ageing in components and systems affects the available resources in an organization and brings about an increased pressure on cost. The phases of ageing analyses are generally the identification of critical components, identification and evaluation of ageing effects, and development of mitigation methods.

This paper presents a broad overview of reliability-based assessment methods such as Failure modes, effects and criticality analysis (FMECA) and Reliability Centered Maintenance (RCM) and how it could be applied to railway projects. EN50126 is often referred to for railway applications in the specification and demonstration of reliability, availability, maintainability and safety (RAMS). FMECA analysis is performed throughout the system lifecycle to identify critical components as part of the ageing analysis. Such analysis highlights the critical components for the system, allowing planned intervention before the failure. RCM is then applied to establish a scheduled preventive maintenance programme resulting in improved component reliability and minimized costs.

## **Bayesian Reliability and Availability Analysis for Hardware Systems described through Continuous Time Markov Chains**

Javier Cano, David Rios Insua  
Universidad Rey Juan Carlos Madrid

Hardware systems are present in many fields of human activity. Continuous Time Markov Chain models are sometimes used in hardware reliability modelling, and they are specially useful in situations in which the system we want to analyze may be modelled with several states through which the system evolves, some of them corresponding to ON states, the rest to OFF states.

We provide here reliability and availability analyses of such systems within the Bayesian framework. The key steps are:

- performing inference for the Markov chain parameters
- performing inference for the Markov chain equilibrium distribution
- computing conditional reliabilities for given ON states and a generic ON state
- computing posterior reliabilities for given ON states and a generic ON state.

As usual, we generally need to turn to simulation approaches to undertake computations. Besides the general approach, we illustrate some standard configurations useful in describing hardware systems.

## **Minimising uncertainties in ageing prediction of in-development complex systems**

Benoit GUYOT<sup>1</sup>, Elisabeth CAYRE<sup>1</sup>, Christophe Bérenguer<sup>2</sup>

Not published yet.

# Probabilistic durability prediction of ageing structural members

Antanas Kudzys, KTU Institute of Architecture and Construction, Kaunas, Lithuania

Ona Lukoševičienė, KTU Department of Construction and Architecture, Kaunas, Lithuania

## 1. Introduction

A durability of load-carrying structural members and their systems, usually, is assessed by implicit recommendations related with long-term experience.

However, a wide range of applied durability issues can be neither formulated nor solved within deterministic analysis methods. The intention of this paper is to present more accurate methodological and probability-based approaches in durability prediction of structural members exposed to extreme actions at persistent design situations.

## 2. Dynamic analysis model

Action effects of members caused by permanent, sustained and extraordinary variable load are discussed. Extreme service or climate action effects as intermittent rectangular wave renewal processes may be reasons of sudden failures of ageing members. The member resistance at initiation and propagation ageing period is treated as stationary and non-stationary processes, respectively. A dynamic model of member durability analysis is presented. It is recommended to simplify the durability prediction by means of the concept of conventional resistances and the method of their piece-stationary approximation.

## 3. Survival probability prediction

According to probability-based approaches (design level III), the time dependent safety margin as the performance of ageing members is considered. The decreasing random sequence of safety margins of structural members is modeled as a generalized geometric distribution. The stochastically dependent cuts of this sequence coincide with extreme loading situations of structures. Probability distribution of extreme action effects is treated as exponential and Gumbel distributions.

## 4. Technical service life

The technical service life of ageing structural members with necessary maintenance but without major repairs or a time in failure at a preset reliability index is treated as main their durability parameter. The effect of ageing rate of materials and action effect features on a technical service life of members is analyzed and illustrated by a numerical example.

## 5. Conclusions

Probability-based approaches help to predict quantitative durability parameters of ageing structural members in sophisticated way. Extreme live service and climate actions may considerably decrease these parameters.

## **Estimation of the durability of dispersion structures in cooling towers**

T. Yalamas and G. Defaux Phimeca Engineering S.A  
J.F. Destrebecq, Université Blaise Pascal  
A. Laudren & B. Clatot EDF CNEPE, Tours, France

Dispersion structures in cooling towers consist of hundreds of reinforced concrete beams. The beams support a complicated system of water pipes, honeycomb packs and water drop collectors in order to enable heat exchange with ascending airflow. The process of ageing of these structures is twofold:

- on the one hand, forces applied to the beams are gradually increasing due to progressive tartar deposition on the honeycomb packs in the course of time;
- on the other hand, the reinforced concrete beams are exposed to degradation due to ambient conditions (high humidity, temperature).

Therefore, operators need reliable methods to estimate the actual condition of an existing structure in order to predict its residual service life, and to determine appropriate ways (inspection, maintenance, repair...) to guaranty and possibly lengthen a safe service life.

The method proposed in this study is based on a combination of several approaches:

- estimation of design margins: a comparison between nominal and actual margins gives an indication on the capability of the structure to fulfil its functions in future;
- prediction of loads evolution: the observed evolution of the tartar load during the past years of service enables to model its expected evolution;
- inspection and measurement of beam deflections: visual inspection and measured deflection give valuable indications on the major cause of degradation of a beam (corrosion, overloading) and enables to classify the structural components in terms of level of deterioration;
- modelling of strength reduction due to ageing: based on the prior conclusion, it is possible to predict the strength reduction of every structural component in the course of time.

The application of this method to existing structures leads to the following conclusions:

- determination of zones where repair is required;
  - proposition of ageing scenarios and estimation of residual service life;
- recommendations for appropriate survey and maintenance.

## Stochastic Ageing Models under Two Kind of Failures

Radim Briš VŠB-Technical University of Ostrava  
 Marko Čepin "Jožef Stefan" Institute Ljubljana

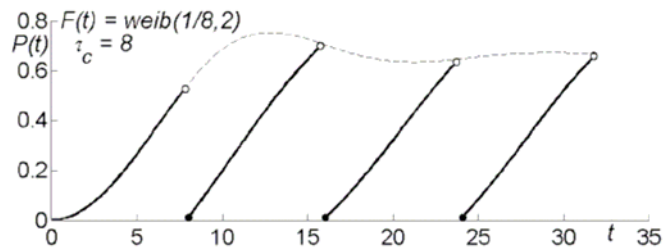
Two kind of concurrent failures are occurring in many practical situations – monitored and dormant. Monitored failures are repaired immediately after they have occurred, whereas dormant failures are detected only by periodical inspections and subsequently repaired. This paper describes the possibilities of their modeling. Time dependent availability is derived in selected cases.

We developed different renewal models taking into account different distributions of failures (Weibull, Erlang, log-normal) respecting ageing process:

- models of monitored failures with negligible renewal time
- ageing models of dormant failures with periodical preventive maintenance

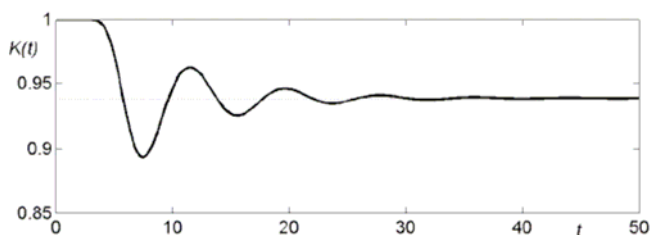
Example:

Time dependent unavailability coefficient for Weibull distribution of failure time and periodical PM (with period  $\tau_c = 8$ )



- alternating renewal process for monitored failures with log-normal distribution of failure time

Example - time dependent availability coefficient for log-normal failure time and exponential repair time



- alternating renewal models with two kinds of failures, etc.

In the case when analytical solution was complicated we used numerical solution to compute renewal function. As basic technique to solve the renewal equation we used Laplace transformation.

## **Lifetime prediction by application of Bayesian methods**

Anna Gabrielsson Vattenfall Power Consultant AB Stockholm

An important task in asset management is to determine when to carry out a renewal of a component or technical system. One parameter that is necessary to take into consideration is the residual lifetime. From an economical point of view it is often advantageous to use the component or system as long as it fulfils a certain performance. In other words renewals are planned towards the end of the equipment's lifetime. To succeed with this matter an accurate estimation of the residual lifetime of the component or system is needed. One way to estimate the residual lifetime is to create a lifetime distribution that describes the probability of reaching the end of the lifetime for the component or system. Classical statistical methods are based on field data alone. When field data is scarce classical statistics do not give significant results. This paper presents a method that combines expert judgements with field data by application of Bayesian methods to create lifetime distributions. The lack of field data is compensated by expert judgements. A lifetime analysis has been carried out for a population of stator windings in hydro power plants in Sweden where the result consisted of lifetime distributions for groups and residual lifetimes for individuals.

## **Probabilistic analysis of behavior and ageing of PEM fuel cell with Integration of degradation models and random temperature**

Moustapha KERDY CEA

Mohamed EID CEA

Raed KOUTA University of Technologie of Belfort-Monbeliard

Eric CHATELET University of Technologie of TROYES

Fuel cell is intended to operate for long time, under many constraints and in aggressive environments. It undergoes degradations and ageing which decrease its lifespan and performances, in addition of the harmful effects of the interior electrochemical reactions on the membrane electrode assembly (MEA). Many are the studies undertaken to control and limit these degradations in order to improve the performances of fuel cell (FC) and the lifespan. These studies are generally focusing on the physical and electrochemical aspects without taking into account the reliability neither the optimization of the maintenance policy. A pertinent probabilistic study should come over several difficulties:

- Lack of data of experience feedback,
- High cost of tests,
- The limited number of available prototypes
- Long durations of the experiments.

The goal is to build a generalized model of FC and to integrate some degradation mechanisms from the literature to bring a behavior model closer to real operation in transportation field. In this paper we consider a random temperature following a normal distribution and analyze its effect on the MEA behavior. There exist several parameters which can be used to assess the performance and the degradation of the FC. We have chosen the FC voltage ( $V_{fc}$ ) and FC lifespan ( $t_s$ ) because of their they easy and direct measurement. After several simulations, a probabilistic analysis was done on the two outgoing parameters,  $V_{fc}$  and  $t_s$ , to find out there probability distributions. This work help to identify components likely to break down. These components will be studied separately to enhance their performances. This model will be used in the optimization of a maintenance policy model adapted to the chosen fuel cell and the observed degradation modes in order to respect availability (productivity) or reliability (safety) constraints with a minimum cost (the dual problem should be also studied).

## **Influential factors on ageing of signal equipment**

**ZIANI Rachid** *SNCF*

The SNCF (French National Railway Company) is a company engaged in continuous progress. As a part of its projects, it seeks to improve the efficiency of signal equipment maintenance.

The maintenance of signal equipment, such as electromechanical detectors, represents an important part of maintenance costs. Moreover, the failure of electromechanical detectors can strongly disturb the rail network. The concerned detectors are placed in the middle of the track and signal passing trains.

Our research project determines the factors that influence the lifetime of such devices. Relying on different databases, describing the infrastructure of the network, the traffic, and the failure of detectors, we propose several statistical models.

Parametric models (Accelerated Failure Time models) and semi-parametric models (Cox models) show that traffic, speed, tonnage, as well as geographical regions influence lifetime of the electromechanical detectors.

A logistic model allows to identify detectors with high risk of failure at a given time, thus allows to optimize maintenance actions.

A Bayesian approach is also tested using a Bertholon model. This model can distinguish accidental failures from ageing failures.

Results from this study help us to better understand the ageing phenomenon and consequently help us to schedule maintenance operations. Thus, some of the incidents can be avoided by preventive maintenance operations.

## Time-variant reliability approach for ageing marine structures

J.Y. Cognard\*, M. Cazuguel & M. Mejri  
Naval Structure Mechanics Laboratory, ENSIETA, France

Reliability assessment of an ageing structure needs to focus attention on the temporal and random character of the data on materials, environmental conditions and loads. Improving the accuracy of this reliability assessment allows better optimisation of planning inspection and maintenance, and, as a consequence, improves safety during an extended service life. A promising way to deal with engineering problems relies on time-variant re-liability methods combined with finite element analysis. Structural design of marine structures which are submitted to complex loading histories requires to take into account the non-linear mechanical behaviour of the material. Irreversible damage can appear in the more stressed parts (fatigue crack...); and, corrosion can also modify the structure behaviour. But those type of simulations lead to solve strongly non-linear time-dependent problems which costs are important. The coupling of the evaluation of structural reliability software with non-linear finite element analyses requires robust mechanical models to ensure accurate results [1]. Therefore suited mechanical models have to be developed in order to limit the numerical cost. The possibilities of the propounded approach are presented through numerical examples. On one hand, the time-variant reliability analysis of a corroded elasto-plastic plate submitted to a stochastic load is presented. We propose a mechanical approach modelling continuously decreases of the safe thickness (corrosion effects [2]) without re-meshing strategies in order to increase the convergence speed of reliability analysis. And on the other hand, a reliability approach of adhesively-bonded assemblies is presented [3]. We propose a strategy with cohesive-zone models in order to reduce the numerical cost and to strongly limit the mesh dependence for crack propagation. This paper emphasizes the feasibility of the combination of time-variant reliability methods [4] and non-linear finite element analysis, highlighting the necessary effort to compute the cumulative probability of failure in terms of accuracy and calculation cost.

[1] Cazuguel, M., Andrieu-Renaud, C. & Cognard, J.Y. 2005. Time-variant reliability of non-linear structures: Application to a representative part of a plate floor. *Quality and Reliability Engineering*, Vol. 22: pp. 101-118.

[2] Guedes Soares, C. & Garbatov, Y. 1999. Reliability of maintained, corrosion protected plates subjected to non-linear corrosion and compressive loads. *Marine Structures* Vol. 12: pp. 425-445.

[3] Mejri M., Cognard J.Y., Davies P., 2006. Development of a reliability approach for the behaviour of adhesively-bonded assemblies in marine applications. 12 European Conference on Composite Materials, Biarritz, Aout.

[4] Andrieu-Renaud, C., Sudret, B. & Lemaire, M. 2002. 'The PHI2 method: A way to compute time-variant reliability'. *Reliability Engineering and System Safety* Vol. 84: pp. 75-86.

## **Does ageing of NPPs require the incorporation of time dependent failure rates in PSA models. Verification using operating experience of emergency diesel generators collected in ZEDB**

J. Blombach AREVA NP GmbH  
K-U. Brahmstaedt, E.ON Kernkraftwerk GmbH  
L. Camarinopoulos, University of Piraeus

The Joint Research Centre started in September 2004 an international network on the incorporation of ageing effects into PSA. The hypothesis is that due to ageing the failure rates of components cannot be assumed to be constant but are increasing with their age. As it is the objective of maintenance to counteract to potential ageing effects so that the failure rate does not increase – at least not significantly – the above hypothesis should be verified with operational experience. For this purpose the failure event data collected in the ZEDB, the reliability database for PSA relevant components of NPPs of Siemens/KWU type PWRs and BWRs, can be used. For the investigation a component collective has to fulfill the following prerequisites

- It is homogeneous
- It contains a sufficient number of failure events

The emergency diesel generators in the power range 2682 – 5000 kW meet these criteria with 89 components and 86 failures to start best.

The failure events were allocated to the age of the diesel generators, the age starting with the date of the commercial operation of the respective plant. Due to the event reporting this resulted in left and right censored data, which had to be evaluated statistically.

For the statistical evaluation the Weibull distribution was assumed, and its parameters  $\alpha$  and  $\beta$  were estimated using the Maximum Likelihood function. After failure, the components were assumed to be as bad as old; renewals have not been considered. This leads to the statistical model of a non-homogenous Poisson process where the rate of occurrence follows a power law like the failure rate of a Weibull distribution. The homogeneity of the diesel collective was improved subdividing it according to the diesel manufacturer.

The parameter  $\beta$  which describes the time dependency was estimated for all sub-collectives to be close to 1, thus indicating that there is no basis to reject the hypothesis of a constant failure rate.

From this investigation it can be concluded that there is no need to complicate the PSA model by the implementation of time dependent failure rate models for which no data from operational experience are available. If it became evident from the statistical evaluation of operating experience that the failure rate of the one or the other component is increasing with

age, the maintenance of these components should be improved rather than implementing generally ageing into the PSA model.

## **DEVELOPMENT OF AGEING MODELS IN PSA STUDIES**

L. Burgazzi ENEA

This note addresses the incorporation of ageing effects within the reliability models of components and systems, both active and passive, to be considered in nuclear power plant probabilistic safety assessment (PSA) studies. This requires, fundamentally, the combination of component stochastic failure mode models (usually represented in the exponential form, independent of the age) and wear-out models, induced by ageing mechanisms causing mechanical degradation and infringing its performance. The approach to the issue is proposed in terms of both the age distributions and the failure rate for the reliability function and the relative models are presented.

The impact of maintenance actions on the reliability and availability models of components is considered as well.

A set of models tailored to the issue is proposed, as a PSA tool, to exhaustively provide a basic framework related to the incorporation of aging effects into the probabilistic safety studies.

## **Models of Aging Equipment in the Probabilistic Safety Assessment**

Marko Čepin "Jožef Stefan" Institute Ljubljana  
Radim Briš VŠB-Technical University of Ostrava

The probabilistic safety assessment is a standardised tool for assessing and improving nuclear power plant safety. The probabilistic models of safety equipment, which represent the standpoint for evaluations, are based on assumption of constant failure rate. The probabilistic models are used within the fault trees, which represent the models of the systems. The fault trees are linked together with the event trees, which model the accident scenarios of the plant and which combine the systems together in an overall model. The new probabilistic safety assessment models, which include information about aging, are developed. Distinguished are several groups of components, which require their unique models. E.g. operating components require different probabilistic model than stand-by components, which operate only in case of demand. The developed models are inserted into the models of the probabilistic safety assessment in order that the aging effects are considered. The models of the small example applications are developed and the results are obtained. The results show a slight increase of risk considering the aging effects. At the same time, the results change the ordering of the most important equipment from aspect of risk decrease and risk increase factors.

## Consideration on the problem of aging of nuclear facilities

A. RODIONOV (JRC PETTEN/NETHERLANDS),

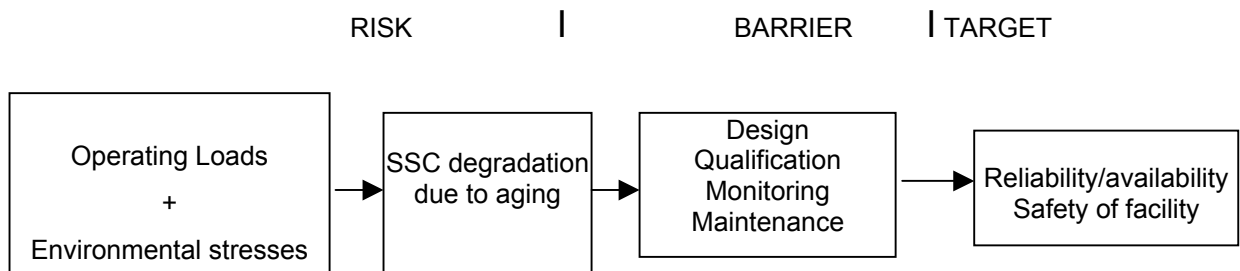
JM. MATTEI (IRSN/FRANCE), [jean-marie.mattei@irsn.fr](mailto:jean-marie.mattei@irsn.fr),

The paper presents a summary of discussions, researches and feasibility studies related to the evaluation of impact of SSC aging to the overall nuclear installation safety.

The following issues are discussed:

- General aspects of aging and aging management,
- Installation lifetime and safety objectives,
- Potential impact of aging to safety on the level of component, system and installation,
- Use of probabilistic approach for aging assessment (PSA level 1).

The diagram provided below schematizes the main areas related to the aging and lifetime management.



### ***Aging and installation safety***

Taking into account the safety objectives specified by INSAG-12, the principal conclusions identify the following issues of safety assessment related to aging:

- Limitation of installation lifetime due to main components and structures (reactor vessel, containment, primary circuit),
- Possible review of initiating events list as well as operating limits and conditions on the basis of operational experience data and results of R&D on materials properties,
- Review of classification of internal and external hazards,

Development of Aging PSA.

## **Corrosion monitoring programmes of NPP safety related components**

Martin BREZINA & Ludovit KUPCA & Jana PETZOVA  
VUJE, Slovak Republic

Corrosion stability monitoring of safety related components is an important task for the safety operation and lifetime extension of NPPs. From the operational experience and from the demands of the national regulatory bodies follows requirements for corrosion behavior monitoring of main structural materials. As the respond to this requirement, several technical solutions have been prepared for the long-term monitoring of NPP materials. These monitoring systems are based on the principle of surveillance samples. All specimens made from original materials are placed into the original environment and loaded with stresses similar to the operational ones. Following monitoring systems are keeping in the operation:

- Corrosion loops in primary circuit are the unique equipments that have been installed in primary circuits of Bohunice Unit-3 NPP and Mochovce Unit-1 NPP and provide the possibility to expose sets of samples in original conditions.
- Monitoring system on the primary flange of the steamgenerator collector features simple equipment enables a long-term exposition of various samples inside the steam generator above the primary collector flange in secondary circuit conditions.
- Monitoring system in RPVs water shielding tank makes possible to expose corrosion samples into the water tank.
- Corrosion monitoring systems placed in spent fuel interim storage pools. The spent fuel interim storage in the NPP Jaslovské Bohunice makes use a wet storing, i.e. the spent fuel assemblies, which are placed in casks, are stored in large water pools. Sets of samples are placed into each water pools and periodically evaluated.

Corrosion monitoring systems provide important information about corrosion situation of both materials and equipments. From the corrosion point of view, used structural materials are stable in given standard condition and make possible to extend the lifetime of NPPs.

## A Predictive Maintenance Policy Based on Two Explicative Variables

Estelle Deloux & Bruno Castanier Ecole des Mines de Nantes  
Christophe Bérenguer Université de Technologie de Troyes  
Thomas Yeung Independent Consultant

We are interested in the modelling and the evaluation of a maintenance policy for a single-unit ageing system with two failure modes function of several measurable quantities. During the last decades, an intensive research activity on maintenance modelling [1] has produced a lot of maintenance models for optimizing the maintenance epochs but few of them are devoted to predictive maintenance strategies. On the other side, statistical process control received a great deal of attention in the quality literature. These two research areas are rarely integrated. However, coordinate statistical process control and preventive maintenance presents economic performance [2, 3].

Let consider a system where the failure mode can be, at least partially, explained by two measurable variables  $X(t)$  and  $Y(t)$ . We assume that  $X(t)$  is stochastically increasing with time and a given maintenance action has to be performed to know its present value, and a continuously-observable variable  $Y(t)$  is stochastically varying with time before a failure and increasing after a failure. The probability of a failure at a given time is estimated with a given function of the values of the two variables at this time. We can easily assume that the probability of failure is increasing with the two variables. The objective of this paper is to discuss about different maintenance strategies which combine monitoring policy, and especially control charts, for the variable  $Y(t)$  and preventive maintenance policy for  $X(t)$  and to estimate their performance by the use of Monte Carlo simulations.

### References

- [1] Wang H. A Survey of Maintenance Policies of Deteriorating Systems. *European Journal of Operational Research* 2002; **139**:469-489.
- [2] C.R. Cassady, R.O. Bowden, L. Liew, and E.A. Pohl. Combining preventive maintenance and statistical process control : a preliminary investigation. *IIE Transactions*, 32 :471\_478, 2000.
- [3] K. Linderman, K.E. McKone-Sweet, and J.C. Anderson. An integrated systems approach to process control and maintenance. *European Journal of Operational Research*, 164: 324\_340, 2005.

## **Ageing management of safety related components of WWER-440 units operated in Slovak republic**

Ludovít KUPČA, Martin BŘEZINA, Jana PETZOVÁ  
VÚJE, Slovak Republic

The main goals and results from the complex research project „ Ageing management and life-time optimization of NPP`s WWER-440“ are summarized in the paper. The schedule of this project was from October 2002 till December 2005. The results of the project are oriented for the operation of Slovak republic Nuclear Power Plants.

The detail structure of this project divided to the main tasks, subtasks and working packages with the milestones and results for realization in operational practice are presented too. As the illustration are presented the specific results from main task No.3 dealing with the ageing of material properties due to the influence of operational environment. These results were prepared as two important projects proposals for:

- irradiation embrittlement monitoring of reactor pressure vessels,
- thermal ageing monitoring of the primary circuit structural materials properties.

The results obtained from the project will be used for the operators of Slovak NPP`s as the base technical arguments for the operational life-time prolongation.