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IDENTIFICATION OF AGEING SIGNS

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Abstract. *Taking into consideration that in analysis we have to deal with many number of NPP components (with a variety of applications), considering also the complexity of ageing processes, and the fact that we have limited resources, there is a need to concentrate the effort on the understanding and managing the safety impact of ageing on key ageing problems and components. The process of identification of ageing signs of the components in order to focus the evaluation effort represents a convenient way of dealing with large information. The paper presents the methods useful in identification of ageing signs, and highlights their advantages and limitations.*

Keywords: ageing, trend, ageing failure mode and effect analysis

1. Introduction

Over the years, the increasing age of components has the potential to deteriorate their performance and by that to jeopardize the operation of the plant in safe conditions.

In order to assure a long and safe operation of the plant, the ageing management should be effective in mitigation of ageing degradation. Measures must be taken to detect ageing degradation and to mitigate it by appropriate maintenance and operational actions.

To evaluate each of plant components in terms of its susceptibility to ageing is a difficult task. Still, we should be aware that the process of evaluation and quantification of ageing degradation for thousand of individual components is not practicable nor is it necessary. Components should be carefully selected and prioritized according to their susceptibility to ageing, in order to maximize the effective use of limited resources and to prioritize the work. The ageing management measure (prevention and mitigation) will be focused mainly on these selected components.

The methods which can be used in determining components susceptible to ageing degradation are the following:

- analysis of operating experience,
- expert judgments.

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The methods are complementary and for the best results they should be used in combination.

2. Analysis of operating experience data

On average, ageing can be considered as one of the important causes of operating events reported. The review of operating experience can be used to identify, correct and mitigate system and component failures from any cause, including the effects of ageing degradation [3].

The analysis of operating experience data permits: [4].

- to identify the extent to which the performance of systems and components has been affected by ageing, and the ageing mechanisms responsible,
- to identify methods of failure detection and the severity of the failures,
- to identify specific ageing failure causes for selected components.

Periodic assessment of databases can provide information on increasing component failure rates, which is sign of ageing.

By interviewing personnel on:

- - equipment problems and ageing possible root causes,
- - anticipated equipment performance or reliability problems,
- - historical ageing problems;

component operating information can be collected and significant ageing sensitive components can be identified.

Identification of important ageing mechanisms and estimation of reliability parameters for system analyses require the following types of data:

- material property,
- normal and abnormal operational stressors and conditions,
- operational test and maintenance data,
- component failure data.

In the process of performing ageing trend investigation, either graphs can be constructed, or statistical analysis of data can be performed.

In addition to looking for trends, the other sources of variation should be identified. If the components have different design, or if they operate in different systems (with different environments), or if they have different test and maintenance procedures, these differences might lead to different failure rates. In this case, the components should be grouped into separate classes, or categories. For each class, the estimate and confidence intervals for λ should be constructed, and plotted side by side, and marked differences should be looked for, in order to see if the data must be split into subsets that must be analyzed separately.

If substantial differences are seen between classes, this fact must be taken into account, and the data should be analyzed separately for each class.

2.1. Graphical method [1], [6]

The type of graph depends on the type of data, either data for the individual failures or binned data.

A trend analysis of the data can be done by calculating failure rates for the components at various ages, and plotting them as a function of time. Once plotted, any increase in the failure rate will become evident, indicating that ageing degradation may be appeared.

The scatter plot can be mentally interpolated to form a line. The slope of the line can be defined as the number of failures divided by number of years, so the slope represents a graphical estimator of the event frequency, λ.

A constant slope, or a straight line, indicates a constant λ. If graph shows that λ was decreasing - the plant was in early stage of its life, but if the slope is larger on the right, the graph shows evidence of deterioration, presumably caused by ageing.

In case of binned data, with component counts and failure counts aggregated into bins, for each bin, an estimate of λ can be made, using the maximum likelihood estimate (MLE) - the number of failures divided by total exposure time for the bin, treating λ as if it were constant within the bin. For each bin a confidence interval for λ will be constructed. After plotting the estimates and confidence intervals side by side, the analyst can look for a trend.

2.2. Statistical analysis of data [1], [6]

In case of large population of components and well doing operating experience data collection, the statistical methods could be applied to identify the appearance of ageing effect to component reliability.

The statistical tests can be divided into two groups: parametrical and non-parametrical. Parametrical tests are more complex but more powerful than non -parametrical ones.

In the application of parametrical methods, is assumed the law of random value distribution, and the accepted hypothesis is checked on the basis of the received data. To make the assumption on the distribution law and to inspect the accepted hypothesis it is necessary to have certain set and volume of the initial data, and unfortunately, this is not always available. Sometimes, this difficulty can be bypassed using non-parametrical tests, which don't apply any assumptions concerning the type of random value distribution.

The hypothesis can give a quantitative answer to the question of whether ageing appears to be present, by measuring the strength of the evidence against the hypothesis H_0: no ageing occurs.

Different statistical tests could be used to validate or to refuse this assumption. Bellow will be described the most used ones, with their advantages and disadvantages, in two cases, when the data contain information on the individual failures and when the data are aggregated in bins.

For data as individual failures, we can use the following tests:

LAPLACE TEST

The method considers the null hypothesis H_0: λ is constant over time, and the alternative hypothesis H_1: λ is an increasing function of time (it assumes that the events tend to occur more at one end of the interval than at the other).

We consider m components, with the i-th component observed from age a_i to b_i and having n_i failures occurring at successive random times during that time period.

Considering T_{ij}, - the random failure times, for i = 1 to m and j = 1 to n_i, if no ageing is occurring, each T_{ij} is uniformly distributed on (a_i, b_i).

Let c_i denote the centre of the i-th interval, $(a_i + b_i)/2$, and let w_i denote the width of the interval, $b_i - a_i$; then $(T_{ij} - c_i)/w_i$ is uniformly distributed on $(-1/2, +1/2)$, with mean 0 and variance 1/12. The sum of all these random quantities,

$$\sum_{i=1}^{m}\sum_{j=1}^{n_j}\left(\frac{T_{ij}-c_i}{w_i}\right) \tag{1}$$

has mean 0 and variance $\Sigma n_i/12$. Therefore,

$$\sqrt{12/\Sigma n_i}\sum_{i=1}^{m}\sum_{j=1}^{n_j}\left(\frac{T_{ij}-c_i}{w_i}\right) \tag{2}$$

has mean 0 and variance 1, and by the Law of Large Numbers it is approximately normally distributed.

The approximation is very good when the T_{ij}'s are large and uniform distributed.

In case when ageing is occurring, more failures are expected late than early, and Expression (2) will tend to be larger than the case when no ageing was occurring, giving the evidence of ageing.

The Laplace test is very good for detecting a wide variety of monotonic trends and consequently it is recommended as a general tool for testing against such alternatives.

Still, the test does not detect erratic changes upward and downward.

INVERSION CRITERIA TEST

The method involves calculating a statistical criterion based on the number of times the failure rate during each defined time interval increases in relation to the others.

The method divides the period covered by the age of the equipment into M equal intervals (t_i, t_{i+1}) and calculates the failure rate λ_i for each i-th interval, as:

$$\lambda = n_i \Big/ \left(\sum_{k=1}^{N_i} \Delta t_k^i \right) \tag{3}$$

where:

n_i – total number of failures observed within the i-th interval,

N_i – number of components been in operation during the i-th interval,

Δt_i – time in operation of k-th component at i-th interval.

If all (N_i) components were in operation during whole interval duration the formula could be re-wrought as:

$$\lambda = n_i / \left(N_i \Delta t \right) \tag{4}$$

For each i-interval (t_i , $t_i + \Delta t_i$), the number of failures recorded within this interval is defined (n_i), and i-ordered sequence of random values ($\{n_i\}$, i=1, 2, ... , M) is considered. Test of $\lambda(t)$ trend is reduced to test of trend for $\{n_i\}$ sequence.

The null hypothesis assumed that: $\lambda_i = \lambda_j$ for all $i \neq j$ (this hypothesis supposes the absence of trend).

Alternative hypotheses are:

H_1: $\lambda_i > \lambda_j$, if $i > j$ (hypothesis of positive trend) and

H_2: $\lambda_i < \lambda_j$ if $i > j$ (hypothesis of negative trend).

The test algorithm of statistic hypothesis of the trend in the sequence of random values $\{n_i\}$ based on inversion test is related to calculation of the total number of inversions A for all members of sequence.

The inversions number A_i for each i-member of the sequence is a number of cases, when $\lambda_i > \lambda_j$ for $i < j$ ($j = i$+1, i+2, ... , M).

$$A_i = \sum_{j=i+1}^{M} h_{ij}, \text{where: } h_{ij} = \begin{cases} 1 \text{ for } \lambda > \lambda_j \\ 0 \text{ for } \lambda \le \lambda_j \end{cases} \quad (5)$$

After calculation of values A_i for each of M-members of sequence $\{n_i\}$, the total number of inversions for all members of sequence is determined as being:

$$A = \sum_{i=1}^{M-1} A_i \quad (6)$$

The hypothesis of a decreasing trend is accepted against condition:

$A > A_U$, downwards trend (reliability is improved with time)
and increasing trend:

$A \le A_L$. case related to ageing phenomenon (ageing impacts to the component reliability)

The following factors could have impact on the analysis results:

- total number of failures (n).

The method could not be applied if the number of failures is insufficient (less then 20 failures).

- number (M) and length (Δt) of considered intervals.

It is supposed that n observations of variable λ i are distributed continuously, independently and identically.

Condition for the constant number of equipment components in division intervals leads to the need to exclude some equipment components and thus results in the loss of statistics. The choice of M depends on the length of interval and period of data collection, and is recommended to adjust the values of M and Δt to avoid a large number of intervals with zero failure statistics (not more then 10% of M).

- quantity of components which are in operation at time interval Δt.

It is recommended to exclude from the analysis the intervals where less then 10 components were in operation.

- intervals with repeated values of failure rates.

In case of a small size of the statistical sample, a considerable part of the division intervals with the same number of failures is obtained – the values are repeated, and this repetition can distort the analysis results under certain conditions.

When the number of such intervals is more then 10% of M it is recommended to use Sean correction for the inversions formula:

$$A = \sum_{i=1}^{M-1} A_i + \text{int}\, 0{,}5 \sum_{i=1}^{M-1} S_i \quad (7)$$

where int 0,5 $\sum_{i=1}^{M-1} S_i$ is an integral part of value 0,5 $\sum_{i=1}^{M-1} S_i$ and

$$S_i = \sum_{j=i+1}^{M} q_{ij} \text{ when } q_{ij} = \begin{cases} 1 \text{ if } n_i = n_j \\ 0 \text{ if } n_i \neq n_j \end{cases} \quad (8)$$

- number of component replacements.

Component replacements have to be taken into account during the initial data treatment. After the replacement a new component with age 0 has to be added to the statistic for failure rates estimation. For the reliable reparable components, in case of only few replacements (less then 3-5% from total number of components) their impact to the trend analysis results is considered negligible.

Advantages of the method are the following:

- is simple to apply (it reveals only the presence or absence of random value trend)
- doesn’t require knowledge of the random value distribution law
- permits to use the statistics from different units

The following should be considered as disadvantages of the method:

- the test provides only qualitative indication about the presence or absence of ageing trend
- the main deficiency of the inversion criteria test is that it gives optimistic results in case of coincidences (equal values) on sequence of estimation values failure rate λ_i (we have on different intervals $(t_i, t_i + \Delta t], (t_j, t_j + \Delta t],\ i \neq j$, the same estimation values of failure rate $\hat{\lambda}_i = \hat{\lambda}_j$).
- uncertainties of inversion criteria test are related to the assumed confidence level

To obtain more credible results of the trend analysis each group should be analyzed by several iterations. For every considered age-interval the lower and upper boundaries of λ_i should be estimated and those age-intervals with high value for uncertainties of failure rate, should be excluded from the analysis.

THE CHI-SQUARED TEST

The test is used to study whether the rate is the same for different cells.

The null hypothesis is H_0: λ is the same in all the data subsets.

The method is to see what kind of data would be expected when λ is constant, and then to see how much the observed counts differ from the expected counts. If the difference is small, the counts are consistent with the hypothesis H_0 that the rate is constant. If, instead, the difference is large, the counts show strong evidence against H_0 (ageing sign).

The method consider x_j and t_j the count and exposure time corresponding to the *j*-th cell, and assume $x = \Sigma x_j$ and $t = \Sigma t_j$.

Assuming H_0 is true, then MLE of λ is:

$$\hat{\lambda} = x/t \tag{9}$$

Assuming the hypothesis of a single rate λ, an estimate of the expected count for the *j*-th cell is:

$$\hat{\lambda} \cdot t_j = e_j \tag{10}$$

The test for equality of rates considered is based on the following calculated expression:

$$X^2 = \Sigma_{jj}(x_j - e_j)^2/e_j \tag{11}$$

X^2 is large if the x_{js} (observed counts) differ greatly from the e_{js} (expected values when H_0 is true), and is small if the observed values are close to the expected values.

When H_0 is true and the total count is large, the distribution of X^2 has a distribution that is approximately chi-squared with $c - 1$ degrees of freedom, where c is the number of cells. If the calculated value of X^2 is large compared to the chi-squared distribution, there is strong evidence that H_0 is false.

The above considerations are valid if the total count is large (if the e_{js} are large). If the e_{js} are small, the chi-squared distribution is not a good approximation to the distribution of X^2.

A chi-squared test based on a larger number of cells will identify much easier the cases when rates are not equal, but this also makes it difficult to satisfy the request for expected cell-counts for the chi-squared approximation. Thus, it is sometimes necessary to make a compromise between expected cell counts and the number of cells.

In case when expected cell-counts are so small that the chi-squared approximation is not recommended, the analyst can increase the number of expected cell, by pooling data in some “adjacent cells”; this pooling of cells could be useful if:

- -the cell counts were smaller,
- -there were engineering reasons for believing that the pooled cells are relatively homogeneous (event rates are similar for many units at a site, more similar than the event rates at different sites).

In case when we have to deal with binned data, the null hypothesis remains H_0: p is the same for all the data subsets, and the alternative is H_1: p is increasing over time.

To compare different classes of components, a chi-squared test can be used as in testing failure rate, with the differences that the data subsets are years or similar bins of time.

CENTROID TEST

In the case of binned data, the easiest test is to divide the data into two segments, corresponding to the early and late portions of the component histories, with approximately half of the exposure time (component-years) in the early segment and the other half in the late segment. Denote these early and late exposure times by s_E and s_L, the total exposure time by $s_T = s_E + s_L$, and the number of failures in the late period by X_L.

If no ageing is occurring, a failure is equally likely at any time, and the total number of failures n, X_L has a binomial (n_T, p) random variable, where

$$p = s_L/s_T \qquad (12)$$

If the ageing is occurring, X_L will tend to be larger.

THE WILCOXON-MANN-WHITNEY TEST

This test is similar in spirit to the Laplace test for a trend in λ□, and is based on the sum of the ranks of the failures.

Supposing that the individual demands are in a known sequence, the null hypothesis is that p is the same for all demands.

Let W denote the sum of the ranks of x failures in n trials.

If x and n - x are both large and if the probability of a failure is the same for the entire sequence, W is approximately normal with mean $\mu_W = x(n + 1)/2$ and variance $\sigma^2 = x(n - x)(n + 1)/12$.

If $Z = (W - \mu_W)/\sigma_W$, is in either tail of the distribution, the null hypothesis should be rejected. If x or $n - x$ is small, statistics books give tables, or statistical computer packages calculate the exact tail probability.

If the evidence justifies further work, a model for the data and for the trend should be assumed. The process of modeling a trend involves detailed mathematics usually performed by computer software.

It can be assumed that the data come from a Poisson process, with a failure rate λ that may be a function of age (several functional forms –linear, log-linear, Weilbull have been assumed in the literature for $\lambda(t)$). [1]

$\lambda(t)$ can be assumed as constant before a period of time named the threshold age t_0, after which the value is increasing following one of the modeling formulas. The threshold age is generally unknown, and must be estimated from the data, even if is difficult to quantify the uncertainty in the estimate of the threshold.

EXPERT JUDGMENTS

Consulting experts opinion represents another way of dealing with ageing signs identifications and estimations. [4] For realistic results, the experts should have access to all the necessary information. Also, the experts involved should have expertise in many relevant technical areas: PSA, component reliability, materials behavior and failure analyses, in-service inspection, operations and maintenance, safety, regulatory, ageing and life extension issues.

An expert panel is useful in the following areas: [5]

- assessing the ageing of plants,
- determination of the importance of ageing of individual components/ component groups on plant risk,
- prioritization of the components taking into account their risk significance of ageing,
- incorporation of understanding of ageing and its effects (definion of components susceptible to ageing list and the contribution of their ageing to plant risk),
- assessing the adequacy of current practices for managing component ageing within acceptable levels of risk.

An analysis technique which is based on the expert opinion is the Ageing Failure Mode and Effect Analysis (AFMEA).

AGEING FAILURE MODE AND EFFECT ANALYSIS (AFMEA)

The AFMEA is a method that may be used to evaluate risk priorities for mitigating known threat-vulnerabilities to ageing.

AFMEA is used to identify potential ageing failure modes, determine their effect on the operation, and identify actions to mitigate the failures. While anticipating every failure mode caused by ageing is not possible, should be formulated a list of potential/ generic failure modes.

The purpose of AFMEA is to study the results or effects of item failure caused by ageing, on system operation and to classify each potential failure according to its severity.

The technique may be performed as a hardware analysis, a functional analysis, or a combination of both.

For each system element, AFMEA can provide answer to the following questions:

- What are the stressors?
- Which are the corresponding ageing mechanisms?
- What are the ageing failure modes for a particular component, caused by a specific ageing mechanism?
- What will happen to the system and its function if the component will degrade due to ageing (failure effects caused by ageing)?

The analysis will identify also the modalities in which the ageing failure can be detected and will specify (if any) the existing protections against significant failures caused by ageing.

The analyst could perform the analysis in two ways:

- he can perform a classical FMEA [2] (or use the results from the previous analysis, if they were available), and after that he can select only the failure modes which are caused by ageing. In this case, the most probable causes associated with the postulated failure mode shall be identified and described. Since a failure mode may have more than one cause, all probable independent causes for each failure mode shall be identified and described.

Each failure mode and output function shall be checked in relation to the following typical failure conditions:

a. Failure to operate at demand.

b. Spurious operation.

c. Failure during operation.

d. Degraded output or operational capability.

- he can perform from the begging of the analysis a selection of failure modes caused by ageing which are possible to appear (this mode requires a carefully selection, for completeness and accuracy of the results), and to evaluate only their effect on the immediate level, on the system, and on the function needed to be performed.

The following discrete steps shall be used in performing an AFMEA:

1. *The definition of system to be analyzed* [2]

Complete system definition includes drawings, charts, descriptions, diagrams, component lists, identification of internal and interface functions, expected performance, and failure definitions.

Functional narratives of the system should include system and part descriptions of each mission in terms of functions which identify tasks to be performed for each mission and operational mode.

The expected mission times, equipment utilization, the functions and outputs of each component, and conditions which constitute system and component failure should be specified.

The operation, interrelationships, and interdependencies of functional entities should be identified for each item configuration.

All system interfaces shall be indicated. Anticipated environmental conditions shall be defined and potential stressors should be identified.

2. *Grouping of components*

Taking into account similar characteristics (similar design, similar operating conditions, similar behaviour), the components should be grouped and for each group should be selected a representative component, which is considered the most sensitive to ageing.

3. *The identification of stress factors for each representative component of each group and associated ageing mechanism*

The analyst should consider all information related to operating conditions, component design and qualification, material properties, and to identify the ageing mechanisms which are possible to appear.

4. *The identification of all potential failure modes caused by ageing and specification of their effect on the immediate function, on the system, and on the mission to be performed*

Potential failure modes shall be determined by examination of item outputs and functional outputs identified in applicable block diagrams and schematics.

5. *The evaluation of each ageing failure mode in terms of the potential consequences*

The probability of occurrence of specific ageing failure should be determined.

Ageing failure effects shall be described and shall also consider the mission objectives, maintenance requirements and personnel and system safety.

A description of the methods by which occurrence of the ageing failure mode is detected by the operator shall be recorded (visual or audible warning devices, automatic sensing devices, sensing instrumentation, other indications, or none shall be identified).

The consequences of each ageing failure mode on system operation, function, or status shall be identified, evaluated, and recorded.

The consequences of each postulated failure affecting the component shall be described along with any second-order effects which result.

The consequences of ageing failure are evaluated by three criteria and associated risk indices:

- severity of potential ageing failure (S),
- probability of occurrence of a potential ageing failure (O),
- probability of detection (D).

Each index ranges from 1 (lowest risk) to 10 (highest risk), and for each of them should be developed specific allocation tables.

The overall risk of each failure is called *Risk Priority Number (RPN)* and represents the product of Severity (S), Occurrence (O), and Detection (D) rankings:

$$RPN = S \times O \times D \qquad (13)$$

The RPN (ranging from 1 to 1000) is used to prioritize all potential ageing failures to decide upon actions leading to reduce the risk, usually by reducing likelihood of occurrence and improving controls for detecting the ageing failure.

6. *The prioritization of components and providing recommendation to reduce ageing failure risk*

A prioritization of components based on RPN value obtained can be performed.

This step should determine recommended actions to address potential failures that have a high RPN. These actions could include specific inspection, testing or quality procedures; recommendation of different components or materials; limiting environmental stresses or operating range; monitoring mechanisms; performing preventative maintenance or changing the frequency of maintenance actions; and inclusion of redundancy.

7. *The documentation of analysis*

The results of the AFMEA and other related analyses shall be documented in a report that identifies the level of analysis, summarizes the results, documents the data sources and techniques used in performing the analysis, specifies analysis assumptions and includes the system definition narrative, resultant analysis data, and worksheets.

The final AFMEA worksheet will contain the following information for each component which was analyzed:

- General information (system, analyst).
- Item name.
- Ageing failure mode.
- Failure cause/ ageing mechanism.
- Ageing failure effect.
- Means of detection.
- Risk assessment (Severity rating/ Probability of occurrence rating/ Detection rating).
- Remarks.

Performing AFMEA permits the identification of most sensitive to ageing components, who will experience most likely the ageing degradations.

The AFMEA will provide quick visibility of the failure modes caused by ageing. The method can be performed anytime in the system lifetime.

The method has the following advantages:

- prioritizes system vulnerabilities to ageing,
- provides guiding in changing of operating condition,

- permits identification of stress factors and provides recommendation for their decreasing,
- emphasizes ageing prevention,
- permits identification of potential component failure modes caused by ageing,
- documents risk induced by ageing and actions necessary to reduce it,
- provides justification for improving testing and maintenance activities.

All recommended actions which result from the analysis shall be justified, and evaluated and documented for implementation or not, after case.
Below is presented an example of RPN estimation for pipe, considering the following specific information:

Stress factors:	Flow
	Water chemistry
	Pressure
	Impurities
	Tensile stress
Ageing mechanisms:	Corrosion
	Vibration
	Erosion

Ageing maintenance practice:

This equipment is periodically inspected. Normal routine/ system walkdown are deemed adequate to detect any deficiencies.

Decrease of efficiency of cooling due to sediments on exterior of the pipe is prevented by operating with 5% of pipe plugged, and by maintaining water quality.

The cleaning of pipe is maintained with water jet to avoid pipe plugging.

Ageing effects:

Corrosion-erosion may result in pipe wall thinning which compromise the integrity of the piping and could result in external leakage.

Large breaks lead to harsh environment and flood with consequential failures of multiple equipment.

Vibrations lead to multiple cracking.

Results

After analysis, it is shown that the pipe rupture obtained the highest RPN compared to other failures considered (see table 1), so the analysis should be focused in finding ways to decrease first the factors which leads to the high value of RPN for this kind of failure. The stress factors that lead to rupture should be diminished, as possible.

Table 1. Example of RPN calculation for pipe specific ageing failures

Ageing Failure	**RUPTURE**	**NO FLOW/PLUGGED**	**CRACKING**
Severity Rating	8	8	2
Occurrence Rating	5	2	5
Detection Rating	5	5	7
RPN	**200**	**80**	**70**

Comments

Data base

- Since the operational data is scattered in a wide range of reporting systems, the consultation of a large volume of technical documents is necessary;
- While the volume of technical data on operating experience can be immense, the quality of the data is very different from sources to sources. Some reports contain detailed root cause analysis insights, while the others have uncertain information on the causes and consequences of failures. The identification of root cause is sometimes difficult to be made;
- Most of available databases does not contain the data needed for the proper evaluation of ageing effects (they do not include data on equipment age, service life or service conditions, maintenance histories of the failed components, or records related to incipient failures);
- Databases should be periodically up-dated in order to ensure that information (materials, service conditions and their interactions) needed to assess the effects of ageing are collected.

Graphs

- Graphs can be constructed very easily. Graph visual examination is sometimes sufficient for identification of ageing trends existence (increasing of failure rates), but they don't give any quantitative estimation about the size of the trends.

Non-parametrical test

- Non-parametrical tests are very simple to apply, but their results have to be always interpreted taking into account engineering considerations;
- If enough data of enough good quality is available, statistical methods could be used successfully, but in negative case, the method is not recommended;
- Some of the models which are widely used, are chosen mainly for their simplicity and convenience, not for their theoretical validity;
- Early failures, modifications or renewals performed could have an significant impact on data;
- Any statistical findings must be interpreted carefully, lack of strong evidence for ageing does not prove that ageing is not occurred, there may just not be enough data to draw firm conclusions.

Expert judgments

- If adequate data are not currently available, the expert opinion process is the only way in which ageing issues assessment can be accomplished;
- Expert panels can be very useful if the participants have good knowledge of reactor safety and information from operating experience;
- A proper expert judgment approach requires a lot of effort and time to be performed.

AFMEA

- AFMEA is useful mostly as a survey method to identify major failure modes caused by ageing. The method doesn't take into considerations the human errors or the passive elements located in non-hostile environments, as well as static or non-loaded element. The multiple failures or subsystems are also not taken into account.
- The technique requires lots of time, money, and effort.

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