Sensitive Incorporation of Ageing Effects into the PSA Model

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Abstract: The paper presents the results of a case study on sensitive incorporation of ageing effects into the PSA model of the Russian PWR - WWER-1000. The possible impact of age-related degradation on the component unreliability, safety system unavailability and on the plant risk profile is demonstrated. The discussion on the sensitive use of PSA to evaluate the structures, systems and components ageing effects on the overall plant safety is provided using the WWER-1000 large LOCA PSA model as an example. Based on the comparison of generic and specific ageing reliability databases used in case study some practical insights, recommendations and limitations for sensitive incorporation of the ageing effects into the PSA model are also discussed. The set of “virtual” reliability data was prepared on the basis of the results of case study and available generic data sources. The data includes time-dependent reliability models for certain mechanical, electrical and instrumentation & control components of the high pressure injection system, accumulator’s injection system and low pressure injection & residual heat removal system. The study was carried out within the framework of the EC-JRC Ageing PSA Network Task 7.

Keywords: Ageing PSA, Ageing Effects, Sensitivity Analysis, NPP, WWER-1000, Large LOCA.

1. INTRODUCTION

The ageing can affect the system and structures only through their components. Consequently, the Structure, System and Component (SSC) unavailability may increase due to the ageing of components. That is why the adjustment of the probabilistic safety assessment (PSA) models on hand and its constant failure and repair rates should not include the change of the models on the higher level than the component level, i.e. the system fault trees (FT) are modified on the level of component ageing degradation by component basic events (BE). The FT could be used in the calculation of the probability of functional event trees (ET), as well as for estimation of initiating event (IE) frequencies. In general, both of the cases have to be considered in the input parameter specification.

An ageing analysis requires more data and more extended models than a standard PSA/reliability analysis. With regard to data, there is a general insufficiency of failure data records for components. Thus, ageing failure rates are estimated from raw and/or generic data and expert opinions, which generally have large associated uncertainties [1].

This most important problem for ageing PSA does not support a direct inclusion of ageing into the existing PSA because of the PSA practitioner’s statement that ageing has already been included in the models, when the constant failure rate is assumed. It is quite difficult to separate it from other causes of components and systems failures. Another fact is that the effects of ageing may contribute to the models and results of PSA less than other important features, which are candidates for improvement of the existing PSA [2].

The lacks of ageing reliability data urge us to set of “virtual” reliability data that are prepared on the basis of the results of case studies and available generic data sources. It means that PSA model uncertainty is increasing with ageing that is not desirable. In such conditions, the reasonable PSA applications for incorporation of ageing effects seem to be the case studies for model’s ageing effects sensitivity analysis (AESA). The most thorough way of treating these uncertainties is to carry out sensitivity studies or uncertainties analysis using different ageing failure rates. An earlier presented methodology for unavailability sensitivity analysis related to ageing is applied [3].

A demonstration of ageing impact to risk and reliability, on the level of system/function unavailability and core damage frequency (CDF) and evaluation of ageing impact to risk profile and importance measures – Birnbaum (B), Fussel-Vesely (FV), Failure Criticality (FC), Risk Increasing Factor (RIF), Risk Decreasing Factor (RDF) should be presented. Depending on the purpose of the calculation the following risk measures is quantified: CDF changing as a function of unit age, modification of risk profile (contribution of initiating event groups to the CDF) as a function of unit age, modification of the list of the dominant minimal cut sets (MCS).

The paper presents the results of a case study on sensitive incorporation of ageing effects into the PSA model of the Russian PWR - WWER-1000. The WWER-1000 ageing 'virtual' data includes time-dependent reliability models for certain mechanical, electrical and I&C components of the high pressure injection system (HPIS - TQ_3), accumulator's injection system (AIS - YT) and low pressure injection & residual heat removal system (RHR & LPIS - TQ_2).

2. AGEING SENSITIVITY OF STRUCTURES, SYSTEMS AND COMPONENTS

2.1. Ageing Effects Sensitivity Analysis

The SSC failure modes potentially important from ageing point of view can be divided in two categories (Figure 1): 1) active and a few passive components failure modes modeled in PSA but their ageing effects could be taken into account (Figure 1a); 2) component failure modes not included in a reference PSA model (Figure 1b). In both cases, some changes in the FT and/or ET structures, creation of new BE, as well as elaboration of time-dependent reliability parameters are needed. In this instance, changes can be made to reliability parameters for BEs. In Risk Spectrum PSA code that is mostly used for calculating SSC reliability and plant risk profile, there is no possibility to specify BE unavailability as a function of time/age, and then to perform a risk analysis of the entire model at different time points [1].

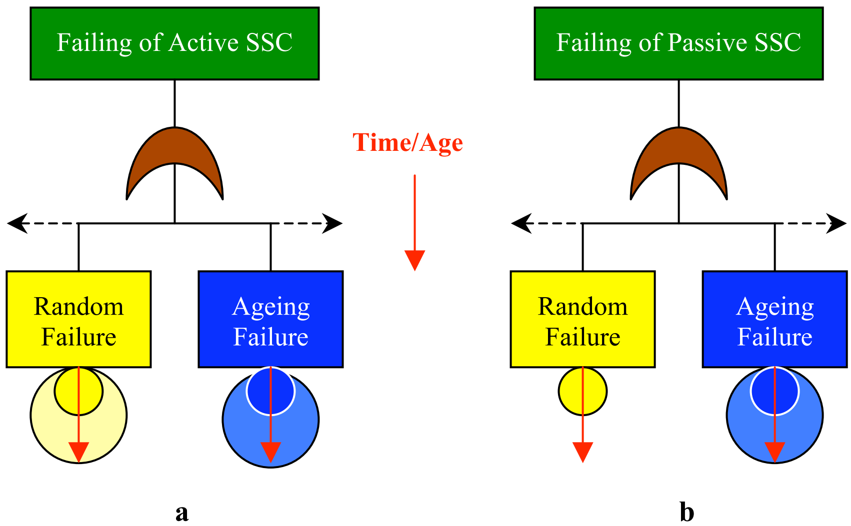


Figure 1: Structure, System and Component Failure Mode Categories

For complex PSA Models of an NPP, it is helpful not only to screen the SSCs susceptible to ageing, but also to determine the reliability parameters that influence PSA model output, and values at which these parameters become influential. It could be denoted as an AESA – hierarchical organization of the most influential input parameters on the output parameters. The AESA aims to quantify the relative importance of input of age-dependent reliability parameters and data with respect to the variability of the PSA model output. The possible issues associated with AESA are connected to:

1) Database and failure, repair/restore models

Different failure and repair/restore rate models can cause significant differences in the calculated results in ageing analysis. Sensitivity studies can help investigate these effects.

2) Test and maintenance model

The sensitivity of unavailability to ageing effects under given test and maintenance practices might be evaluated as well.

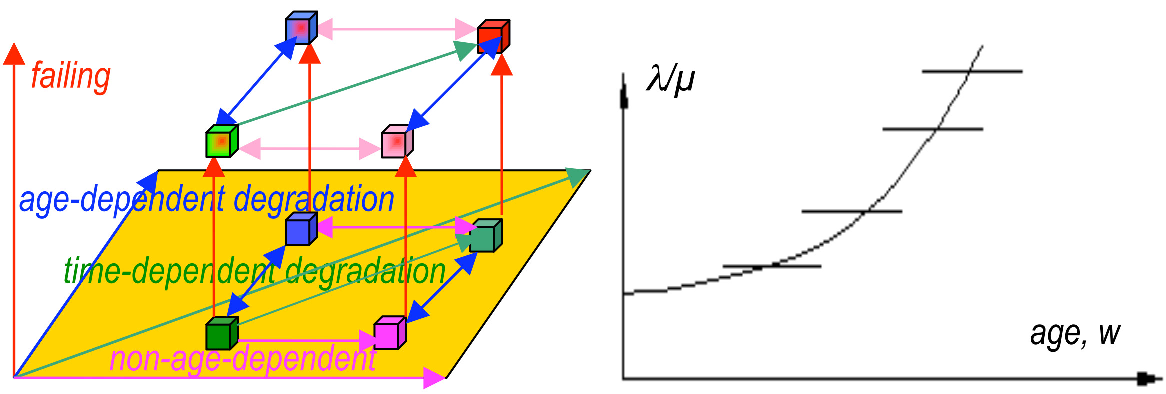
2.2. Cumulative vs. Ageing Degradation

The PSA models are updated periodically and taking into account the ageing that affect the reliability of one or more SSCs. The regulators urge plant operators to update and calculate more frequently risk models in order to check, catch and incorporate as well degradation as ageing processes. The ageing can affect the systems and structures only through their components. Consequently, the SSC unavailability may decrease due to the component ageing degradation.

The difference between age and time is that age generally incorporates the effect of the surveillance, maintenance, and replacement of the subcomponent or whole component, while the time incorporates non-ageing degradation as well. The ageing of the component does not proceed at the same speed as that the actual time (Figure 2a) [4].

When the whole component is replaced, the age of component starts over again from a value of zero but the time does not. In the case of the replacement of specific subcomponents, the age of the component takes a partially restored value, however time remains unchanged. Preventive maintenance actions, such as lubricating bearings, will not change the age of the component since subcomponents are not replaced, but will slow the component ageing process. Therefore, the component failure rate versus time does not show an ageing effect while the component failure rate versus age can show it.

Component ageing degradation is defined as cumulative degradation that occurs during a component's lifetime and can lead to a loss or impairment of its function. The dynamic description of ageing component degradation could consist of many ageing states, multiple failure modes and transitions between these discrete basic events. All of these transitions are implemented in time, so they are time-dependent and age-dependent. However, the age-dependent reliability data could not be collected separately from other non-ageing degradation processes (Figure 2a) and considering data uncertainty the ageing contribution could be almost negligible [2]. Consequently, the age-dependent reliability models (failure & repair rates - λ_i & μ_i) should be constructed based on the temporary local changes and reconstructions of SSCs (Figure 2b). They could be introduced into the equipment, system and plant models step up to end of its lifetime without separation of different degradations.



a b

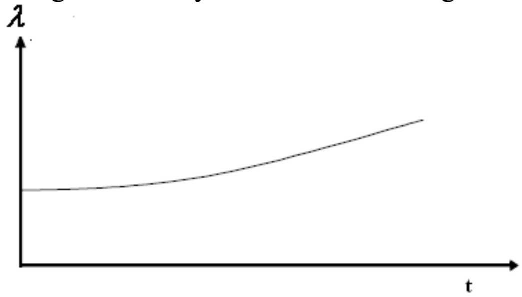
Figure 2: Possible Separation of Degradation Processes and Proposed Incorporation of Ageing

2.3. Age-dependent Reliability Models for Different Component Type and Category

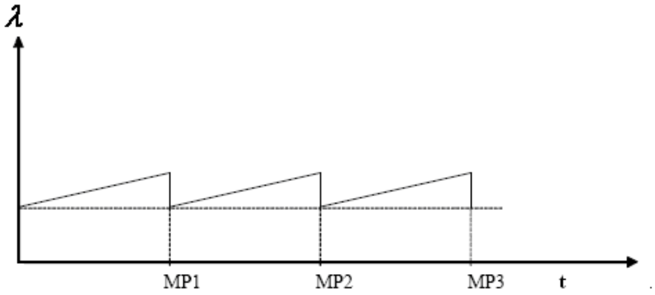
The age-dependent reliability models for different component types and restoring are presented on Figure 3a, 3b, 3c and 3d, where: MP – maintenance period; λ – failure rate/intensity; t – time.

The age-dependent reliability model for complex component type or system is presented on Figure 4, where: MP – maintenance period; λ – failure rate/intensity; t – time/age; T_0 – threshold time at which ageing starts, T_0=t-w, w - age).

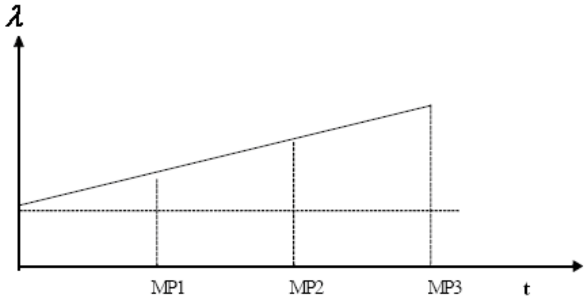
Different ways to describe the age-related degradation and strength reduction for different component categories and by different functions growing in time are used.



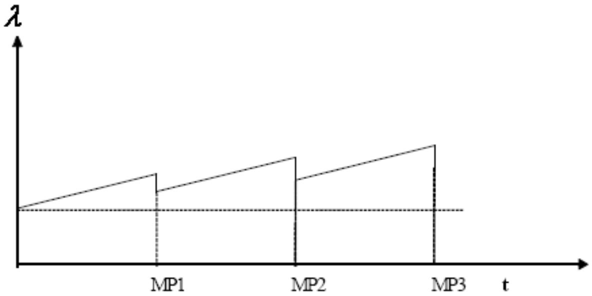
a. Electrical and I&C Components



b. Mechanical Component Restored "As New"



c. Component Restored "As Old"



d. Component Restored Partially

Figure 3: Failure Rate Models of Different Ageing Component Types

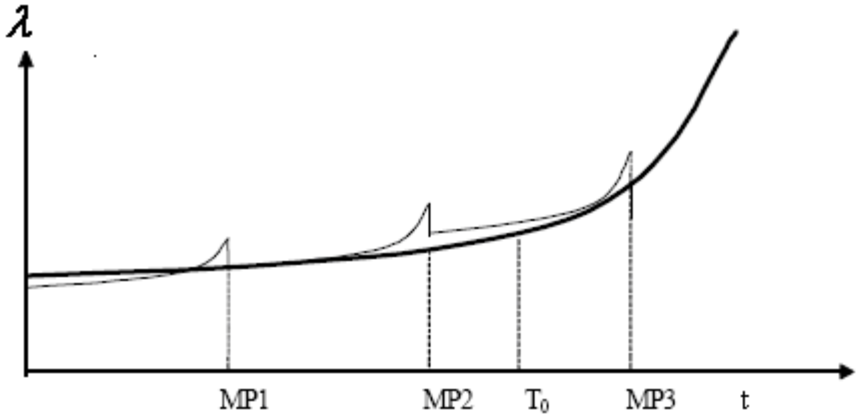


Figure 4: Failure Rate Model of Complex Component or System

3. UNAVAILABILITY SENSITIVITY ANALYSIS TO SYSTEM AGEING

3.1. Selection of Method for Ageing Consideration

The basic methods for ageing consideration are Weibull, exponential and linear methods. These methods include mathematical parameters, for which it is possible to obtain appropriate data, however the PSA software do not use such parameters. It makes these methods more difficult for ageing incorporation into the PSA, modeled by current software as Risk Spectrum, and their use should not be widely applicable.

The NPP PSA probabilistic safety assessment does not directly include consideration of ageing. However, the extension of the existing PSA models, based on living PSA concept, with addition of an independent contribution of ageing degradation to other degradation would be the easiest solution. The deficiency of such approach would be the fact that the contributions of ageing and non-ageing degradation are undistinguishable and may not be independent.

Stepwise constant failure rate method assumes the failure rates or failure probabilities of equipment are constant (mean value) in the determined time interval $\{t_i, t_{i+1}]$. They increase in the next time interval $\{t_{i+1}, t_{i+2}]$ according to one of selected above method for their evaluation due to ageing [2].

Selected methods for consideration of ageing are presented in the following figures.

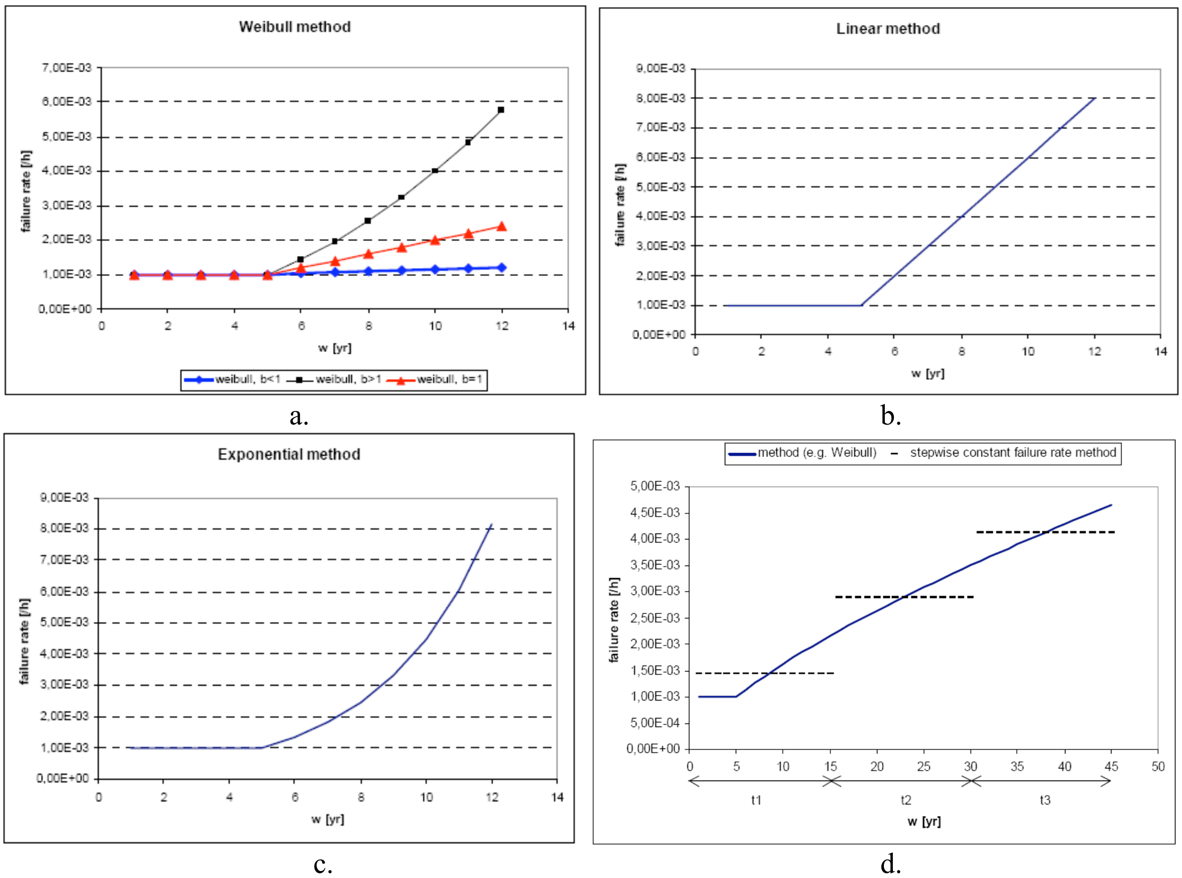


Figure 5: Weibull, Exponential, Linear and Stepwise Constant Failure Rate Models [2]

The linear ageing failure rate models for unrepairable equipment:

$$\lambda(w) = \lambda_0 + \alpha w \qquad (1)$$

where $w=(t-T_0)$ is the age, t is the global time, λ_0 is the pre-ageing failure rate of a new component) T_0 is the threshold time at which ageing starts, α is the rate of ageing and $\lambda(t)$ is the total failure rate.

Some of the results for the ageing failure probability do not agree with linear ageing model, e.g. flow accelerated corrosion. In such cases the two-parameter Weibull ageing failure rate model is chosen:

$$\lambda(w) = \lambda_0 (\frac{w}{T_0})^{\beta} \quad (2)$$

where $\alpha = 1/[(1+\beta)T_0]$ is a scale parameter, β is a shape parameter and T_0 is a location parameter

Another possible ageing model is exponential model. The failure intensities for hare given:

$$\lambda(w) = \lambda_0 . \exp(\alpha . w) \quad (3)$$

α - exponential scale parameter; λ_0 - initial constant failure rate; T_0 - threshold age after which the failure rate increases.

3.2. Mathematical Formulation of Specific Component Ageing Database

The evaluation method for mathematical formulation of ageing from two successive results of PSA follows the mathematical formulation about components ageing rates of TIRGALEX data base. It is the following [2].

$$\Delta\lambda_i = \lambda_i - \lambda_{i0} \quad (4)$$

λ_{i0} is a failure rate of equipment *i* (no ageing considered); λ_i is a failure rate of equipment *i* with ageing considered; $\Delta\lambda_i$ is the increase of failure rate of equipment *i* due to ageing.

$$\Delta q_i = q_i - q_{i0} \quad (5)$$

q_{i0} is an unavailability of equipment *i* (no ageing considered); q_i is an unavailability of equipment *i* with ageing considered; Δq_i is the increase of unavailability of equipment *i* due to ageing.

For tested equipment:

$$a_i = \frac{6\Delta q_i}{(\frac{2}{\lambda_{i0}} - T_i)T_i} \quad (6)$$

a_i is a rate of ageing degradation process in equipment *i*; T_i is a test interval of equipment *i*.

For equipment that is not tested:

$$a_i = \frac{\Delta q_i}{2(w+T_0)^2} \quad (7)$$

$(w+T_0)$ is facility lifetime.

3.3. Adapted Methodology for Determining Sensitivity to SSC Ageing [3]

In order to characterize the unavailability impact of component ageing effects, it is necessary to determine the age dependent nature of the change in system unavailability. That is

$$I_A = \frac{\partial Q}{\partial w} \quad (8)$$

where I_A is an unavailability impact of ageing, and Q is the system unavailability.

The system unavailability is a function of the component failure rate λ; for the study of ageing, the failure rate is a function of age w. By the chain rule, changes in system unavailability are expressed as:

$$\frac{\partial Q}{\partial w} = \frac{\partial Q}{\partial q_i} \cdot \frac{\partial q_i}{\partial \lambda_i} \frac{\partial \lambda_i}{\partial w} \qquad (9)$$

The unavailability impact due to ageing can now be separated into two distinct parts:
The effects of changes in the component failure rate (the first two terms of the right hand side of Eq.9);
Age dependent effects on the component failure rate (the third term of the right hand side of Eq.9).

We define the unavailability ageing sensitivity to failure rate as

$$g_i = \frac{\partial Q}{\partial \lambda_i} = \cdot \frac{\partial Q_i}{\partial q_i} \frac{\partial q_i}{\partial \lambda_i} \qquad (10)$$

The first term of the equation, the partial derivative of system unavailability with respect to component unavailability, is equal to the Birnbaum measure. This is a measure of the component failure impact on system unavailability and it can be computed by changing the unavailability of the component in the system unavailability equation to unity and determining the change in system unavailability.

The unavailability sensitivity to ageing is determined for the rate of unavailability change in terms of the component unavailability changes:

$$\frac{dQ}{dw} = \sum_i \frac{dQ}{dq_i} \cdot \frac{dq_i}{dw} \qquad (11)$$

where $\frac{dq_i}{dw}$ = the rate of change with age of component unavailability q_i

Each term in the sum on the right hand side of Eq. 11 gives the contribution of the ageing of each specific component to the unavailability change. The component ageing unavailability sensitivity contribution is denoted by θ:

$$\theta = \frac{dQ}{dq} \cdot \frac{d(q - q_0)}{dw} \qquad (12)$$

The component ageing system unavailability sensitivity contribution is equal to the importance of the component, multiplied by the extra rate of change of the component unavailability due to ageing.

The total rate of unavailability increase due to ageing given by Eq. 11 is then simply the sum of the ageing system unavailability sensitivity contributions:

$$\frac{dQ}{dw} = \sum_i \theta_i = \left(\frac{dQ}{dt} \right)_A \qquad (13)$$

In general, the system unavailability of the component dQ/dq is also age dependent and is changing with time and age.

For many applications, the ageing and non-ageing unreliability or unavailability is less than approximately 0.1 (q, $q_0 < 0.1$).

Then to the first order, the unreliability sensitivity θ to an ageing component that is unrepairable is simply the reliability importance of the component *dQ/dq*:

$$\theta \approx \frac{dQ}{dq}.[\lambda(w+T_0)-\lambda_0] \qquad (14)$$

Then to the first order, the unavailability sensitivity θ to an ageing component that is restorable or repairable is simply the availability importance of the component *dQ/dq*:

$$\theta \approx \frac{dQ}{dq}.[\lambda(w)-\lambda_0] \qquad (15)$$

where $w=t-\tau$, τ is restoration/renewal time and test interval t_c, $t_c>\tau$.

The variety of time/age dependent component failure rate models can be used for treating potential ageing effects (Weibull, gamma and truncated normal distributions).

The first term of the equation, the partial derivative of plant risk (core damage frequency – CDF) with respect to system/equipment unavailability, is equal to the importance measure. This is a measure of the system failure impact on plant risk and it can be computed by changing the unavailability of the system/equipment in the plant risk model equation to unity and determining the change in plant risk.

$$\Delta CDF = \sum_i S_i \Delta q_i + \sum_{i>j} S_{ij} \Delta q_i \Delta q_j + \sum_{i>j>k} S_{ijk} \Delta q_i \Delta q_j \Delta q_k + \ldots + S_{12\ldots n} \Delta q_1 \Delta q_2 \ldots \Delta q_n \qquad (16)$$

S_i is an importance of system/equipment *i*.

4. CASE STUDY: LARGE LOSS OF COOLANT ACCIDENT AGEING PSA MODEL

A four-loop WWER-1000 PSA model for a Large Loss of Coolant Accident Initiating Event (LLOCA IE) was considered as a reference model. The event tree model (see Figure 6) developed taking into account the following factors:

- operational state: power operation and hot shutdown,
- brake location (100<Dy≤850mm): hot legs or cold legs.

4.1. Description of Event Tree and Fault Trees of Safety Systems in the Model

In order to demonstrate the impact of ageing effects on the system level the AIS-YT, HPIS-TQ_3 and RHR&LPIS-TQ_2 were considered. In case of LLOCA: the TQ_2 assures the residual heat removal from the reactor core. This safety function is considered in all Event Trees selected for the study; the TQ_3 and YT maintain the water inventory in primary circuit and sub-criticality by injection H_3BO_3 al from the reactor core. The safety function of TQ_3 is also considered in all event trees selected for the study but with different criterion (e.g. 1 of 3 pumps). The safety function of YT is considered only in LLOCA event tree.

4.2. Implementation

The procedure of modifying the existing PSA reference model includes the following steps [1]:

1) identification the BEs which correspond to the components sensitive to ageing (importance measuring: FV; FC; RDF; RIF);
2) creation of House Events (HE) for the same model with three different databases to trigger the analysis cases and activate the exchange events for each particular time point where the CDF calculation has to be done (for present Case Study: 8, 14 and 20 years of operation);

Large LOCA 100<Dy≤850mm	**Maintain water inventory in primary circuit**		**Residual heat removal**	**№**	**Freq**	**Cons**
	Injection H_3BO_3 from the accumulators	**Injection H_3BO_3 by the LPIS**	**Injection H_3BO_3 by the HPIS**			
IE LB LOCA	2/4 YT	1/3 TQ2	2/3 TQ3			

Figure 6: Large LOCA Event Tree of WWER-1000 (20 years)

3) specification of four exchange events, for each BE identified on the step 1; each exchange event corresponds to the component unavailability at the time point 8, 14 and 20 years in operation and it is linked to the corresponding HE;
4) determination of attributes for the created exchange events taking into account failure mode, operating state, unit age considered for calculation, test and maintenance strategy, type and parameters of reliability model;
5) specification of the parameters (failure rate and/or probability), linking them to the exchange events and input the initial values for the point estimations and distribution functions;
6) creation of a correspondent CCF group for each exchange event in case when initial BE is considered for the CCF group; the CCF model parameters (e.g. β-factors or MGL) remain the same in the CCF group modeling. CCF failure probability, then, changes with the unit age proportionally to the changes in a probability of independent failure;
7) quantification of the CDF for a particular time point as soon as all modifications for all identified components and BEs are made; For each analysis case in a Boundary Condition Set specification the corresponding House Event was set up as “true”.

Depending on the purpose of the calculation the following risk measures could be quantified:

- CDF changing as a function of unit age,
- modification of risk profile (contribution of IE groups to the CDF) as a function of unit age,
- modification of the list of the dominant MCS,
- changing of risk importance measures.

4.3. Case Study Results

The Tables 1 and 2 demonstrate the change in importance measuring for different ages of equipment modeled in LB LOCA Case Study.

The comparison between linear ageing rates for some components of the TRIGALEX database and ageing database of components modeled in Case Study is shown on Table 3.

The plant level effect for the Large LOCA IE is calculated by Ras 3% of CDF in all plant operating states (POS) of PSA level 1 of Kozloduy NPPP. These POSs contain CDF in power and shutdown operational conditions and fuel storage tank damage frequency for each of two units with WWER-1000 as well. The total change of CDF for Large LOCA in POS0 (full power operation) for last six years (for 20 and 14 years) is calculated as $\Delta CDF_{LLOCA}=CDF_{20\ years}-CDF_{14\ years}$ = 1.67E-7 – 1.76E-7 = -9.0E-9. It confirms that large scale modernization on the both of Kozloduy NPP units succeeds to prevent the SSC ageing processes and to reduce the overall plant risk.

Table 1: Identification (ID) and Importance Measures of LB LOCA Case Study for 14 years

No	ID	Value	F-V	FC	RDF	RIF
1	LB_LOCA	1,000E-05	1,000E+00	1,000E+00	9,990E+99	9,990E+99
2	YTS10-D-CCF	1,040E-03	9,454E-01	9,454E-01	1,831E+01	9,091E+02
3	TQ32S04-O	3,152E-02	4,332E-02	4,316E-02	1,045E+00	2,326E+00
4	TQ12S04-O	3,152E-02	4,330E-02	4,314E-02	1,045E+00	2,325E+00
5	TQ22S04-O	3,152E-02	4,330E-02	4,314E-02	1,045E+00	2,325E+00
6	QF31	2,960E-03	4,068E-03	4,065E-03	1,004E+00	2,369E+00
7	QF11	2,960E-03	4,066E-03	4,063E-03	1,004E+00	2,369E+00
8	QF21	2,960E-03	4,066E-03	4,063E-03	1,004E+00	2,369E+00
9	TQ32D01-S	1,560E-03	2,144E-03	2,072E-03	1,002E+00	2,326E+00
10	TQ12D01-S	1,560E-03	2,143E-03	2,071E-03	1,002E+00	2,325E+00
11	TQ22D01-S	1,560E-03	2,143E-03	2,071E-03	1,002E+00	2,325E+00
12	TQ32D01-KIP	8,120E-04	1,116E-03	1,078E-03	1,001E+00	2,326E+00
13	TQ12D01-KIP	8,120E-04	1,116E-03	1,077E-03	1,001E+00	2,325E+00
14	TQ22D01-KIP	8,120E-04	1,116E-03	1,077E-03	1,001E+00	2,325E+00
15	TQ32D01-R	6,478E-04	8,903E-04	8,596E-04	1,001E+00	2,326E+00
16	TQ12D01-R	6,478E-04	8,899E-04	8,592E-04	1,001E+00	2,325E+00
17	TQ22D01-R	6,478E-04	8,899E-04	8,592E-04	1,001E+00	2,325E+00
18	TQ32D01-KIP1	5,390E-04	7,408E-04	7,152E-04	1,001E+00	2,326E+00

Table 2: Identification (ID) and Importance Measures of LB LOCA Case Study for 20 years

No	ID	Value	F-V	FC	RDF	RIF
1	LB_LOCA	1,000E-05	1,000E+00	1,000E+00	9,990E+99	9,990E+99
2	YTS10-D-CCF	1,040E-03	9,930E-01	9,930E-01	1,423E+02	9,548E+02
3	TQ32D01-S	5,700E-03	1,810E-03	1,797E-03	1,002E+00	1,313E+00
4	TQ12D01-S	5,700E-03	1,806E-03	1,793E-03	1,002E+00	1,313E+00
5	TQ22D01-S	5,700E-03	1,806E-03	1,793E-03	1,002E+00	1,313E+00
6	TQ32D01-R	4,072E-03	1,293E-03	1,282E-03	1,001E+00	1,313E+00
7	TQ12D01-R	4,072E-03	1,290E-03	1,279E-03	1,001E+00	1,313E+00
8	TQ22D01-R	4,072E-03	1,290E-03	1,279E-03	1,001E+00	1,313E+00
9	QF31	2,960E-03	9,398E-04	9,374E-04	1,001E+00	1,316E+00
10	QF11	2,960E-03	9,378E-04	9,354E-04	1,001E+00	1,315E+00
11	QF21	2,960E-03	9,378E-04	9,354E-04	1,001E+00	1,315E+00
12	TQ43S03-DO	2,445E-03	7,763E-04	7,739E-04	1,001E+00	1,316E+00
13	TQ41S03-DO	2,445E-03	7,747E-04	7,723E-04	1,001E+00	1,315E+00
14	TQ42S03-DO	2,445E-03	7,747E-04	7,723E-04	1,001E+00	1,315E+00
15	TQ32S04-O	1,510E-03	4,796E-04	4,742E-04	1,000E+00	1,313E+00
16	TQ12S04-O	1,510E-03	4,786E-04	4,732E-04	1,000E+00	1,313E+00
17	TQ22S04-O	1,510E-03	4,786E-04	4,732E-04	1,000E+00	1,313E+00
18	YTS09-D-CCF	3,000E-07	2,864E-04	2,861E-04	1,000E+00	9,548E+02
19	YTS0910-D-CCF	3,000E-07	2,864E-04	2,861E-04	1,000E+00	
20	YT3S09-D-CCF	3,000E-07	2,864E-04	2,861E-04	1,000E+00	9,548E+02

5. CONCLUSIONS

The process of sensitive incorporation of ageing effects into PSA model has been demonstrated using the Risk Spectrum PSA1 model (Version 1.1.0.1) on the component, system, functional, initiating event and plant levels.

The results of the Case Study (WWER-1000 Large LOCA) give evidence that the ageing contributors should be treated distinctively on the basis of importance measures, system unavailability, dominant accident sequences and IE CDF portions in the overall plant risk (total CDF).

Table 3: Ageing Rates Comparison of TRIGALEX, WWER and PWR Components

Component	TRIGALEX	WWER-1000	Comments
	Ageing rate, per hour per year		
AC bus	1.0E-09	5.7E-09/5.8E-09	
Battery	3.0E-07	1.8E-06	Replaced
Check Valve	4.0E-09	9.6E-11/1.0E-10/1.25E-09/2.6E-08	Varied
Circuit Breaker	2.0E-08	2.05E-08	
Diesel Generator	3.6E-06	-	No ageing
Motor Driven Pump	2.0E-07/8.3E-08	-/2.2E-09/1.2E-7/5.1E-5	Varied
Motor Operated Valve	3.6E-06	5.1E-10/1.53E-9/8.56E-9	Varied
Safety/Relief Valve	7.0E-07	-	No ageing
Transformer	2.0E-09	2.25E-08	
DC Bus	1.0E-09	3.3E-09	
Relay	3.0E-07	4.5E-07	
Filter		-	No ageing
Heat Exchanger		-	No ageing
Tank		-	No ageing

Considering sensitive incorporation of ageing effects into PSA models can help in the selection, prioritization of SSCs susceptible to ageing, improving maintenance measures, replacing important components and performing consistent ageing management as a part of a risk-informed decision-making process.

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