Application of EPRI RI-ISI Methodology for In-Service Inspection of Safety System Pipes at Ukrainian NPPs

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1. INTRODUCTION

The work on adaptation and transfer of the state-of-the-art risk-informed in-service inspection (RIISI) technology to Ukrainian NPP staff and support organizations has been initiated by the National Nuclear Energy Generating Company "ENERGOATOM"- Ukrainian Utility - in year 2001 in the frame of International Nuclear Safety Program sponsored by the US DOE. The need to promote the risk-informed approach to in-service inspection of pipes at nuclear power plants (NPPs) was identified by State Nuclear Regulatory Committee of Ukraine - Ukrainian regulatory body – in year 2004 as a limited pilot study for VVER-1000. The purpose of this pilot study funded by Ukrainian regulatory body was an investigation of possibility for effectiveness of RIISI methodologies based on existing PSA results and ISI practice.

The main tasks of this study were considered as a comparative analysis of the most effective RIISI methodologies (Electric Power Research Institute (EPRI) and Westinghouse Owners Group (WOG)), adaptation of the RIISI methodology to Ukrainian NPPs in general, including collection of pipe failures information with data analysis, and application of this methodology to in-service inspection of main feedwater supply system at Ukrainian NPP units. The main results of this pilot study are discussed in this paper.

2. COMPARATIVE ANALYSIS OF RIISI METHODOLOGIES

The comparative analysis of the most effective RIISI methodologies (EPRI and WOG) has been carried out during the first phase of the Ukrainian regulatory body study. The description of EPRI methodology is referenced to report [1] and WOG methodology – to report [2]. The EPRI methodology had been presented to Ukrainian organizations by the Pacific Northwest National Laboratory (PNNL) experts in year 2003 in Richland, USA.

From the comparison of RIISI methodologies it was concluded that both methodologies can be applied at Ukrainian NPPs, but for the effective usage of each methodology different requirements must be met. Thus, pipe failure data must be collected and analyzed for application of EPRI methodology with subsequent risk matrix correction.

SRRA code validation is necessary for WOG methodology application. In addition necessary experimental data must be obtained for SRRA code effective application.

Finally, it was concluded that EPRI RIISI methodology is simpler and the most appropriate one for Ukrainian NPPs. This is because of minimum structural reliability calculations necessary for EPRI approach application, so one can use this approach without application of specific structural reliability codes. Also the adaptation of EPRI methodology deals with statistical analysis of the specific in-service inspection data targeted for risk matrix correction. For that purpose VVER-specific safety significant piping failure data were collected and analyzed.

3. ANALYSIS OF THE UKRAINIAN NPP PIPING FAILURE DATA

In accordance with EPRI RIISI methodology the risk, associated with a pipe segment failure, is defined as a combination of the potential for pipe rupture and the consequences of such a rupture [3]. Pipe rupture potential is related to the rupture rate due to the degradation mechanisms that potentially exist in given pipe. Rupture consequences are related to the Conditional Core Damage Probability (CCDP). The EPRI RIISI approach includes procedures for evaluation of pipe rupture potential and assessment of pipe ruptures consequences in a form to be easily applied by utility engineers with tools and information that is readily available.

An approach of service data analysis is used in EPRI RIISI methodology to quantify pipe failure frequencies due to different degradation mechanisms. During the second phase of the Ukrainian regulatory body study the VVER piping failure data were collected and analyzed. The data sources were Organization for Economic Cooperation and Development (OECD) Pipe Failure Data Exchange (OPDE) database [4] and Ukrainian NPPs in-service inspection experience. The data collected was classified by the criteria of failure type (cracks/leaks, leaks, failures (large leaks), ruptures) and type of degradation mechanism: corrosion fatigue (CF), thermal fatigue (TF), stress corrosion cracking (SCC), corrosion attack (COR) or local corrosion (LC), flow accelerated corrosion (FAC), vibration fatigue (VF), design and construction defects (D&C), other (OTH), unknown mechanism (UNK). VVER pipe failure data collected are presented in Table 1.

Table 1 - VVER pipe failure data (OPDE data and Ukrainian NPP operational data)

Degradation mechanism	**Failures (all types)**	**Ruptures**
CF	7	2
TF	4	–
SCC	25	–
COR	10	–
WH	2	2
FAC	62	14
VF	43	10
D&C	26	2
OTH	2	1
UNK	26	1
TOTAL:	**207**	**32**

The Bayes' approach application makes it possible to estimate pipe failure rates due to different degradation mechanisms and to carry out risk matrix correction. An approach to calculate Bayes' estimates for pipe rupture rates is outlined below.

In accordance with EPRI approach [3] all the failures were classified into two categories: ruptures and leaks (all failure types except ruptures).

Let us denote $\lambda\{F\}$ as total frequency of pipe failure F. $\lambda\{F\}$ is a mean value of failures numbers happened per reactor year. Total failure frequency can be presented as a sum of failure frequencies due to each of degradation mechanisms (CF, TF, SCC, COR, WH, FAC, VF, D&C, OTH, UNK):

$$\lambda\{F\} = \sum_j \lambda_j\{F\}, \qquad (1)$$

where $\lambda_j\{F\}$ - the frequency of pipe failure due to degradation mechanism j.

In accordance with EPRI approach the features that determine the danger of each degradation mechanism are:

- potential for rupture;
- relative rate of rupture.

The potential danger for each of degradation mechanisms is estimated by the criterion of rupture rate.

Taking into account that each degradation mechanism can be characterized by certain relationship between the failure and rupture events (the set of rupture events can be considered as a subset of failure events), the frequency of pipe failure due to degradation mechanism j can be estimated from the following expression:

$$\lambda_j\{R\} = \lambda_j\{F\}P_j\{R \mid F\} \tag{2}$$

where $\lambda_j\{R\}$ is a rupture frequency due to degradation mechanism j, $P_j\{R \mid F\}$ - the conditional probability that a pipe failure happened due to degradation mechanism j will be a rupture.

Based on that the problem of rupture frequencies estimation can be defined as a task to develop statistical relations between the total set of in-service pipe failures and the set of ruptures. This problem can be solved based on statistical analysis of in-service inspection data, specific for the NPPs of a given type. Simple point estimates of the above relations between the events of failures and ruptures can be obtained from expressions (3)-(5) below:

$$\lambda_j\{F\} = \frac{n_j\{F\}}{T}, \tag{3}$$

$$P_j\{R \mid F\} = \frac{n_j\{R\}}{n_j\{F\}}, \tag{4}$$

$$\lambda_j\{R\} = \frac{n_j\{R\}}{n_j\{F\}}\frac{n_j\{F\}}{T} = \frac{n_j\{R\}}{T}, \tag{5}$$

where $n_j\{F\}$, $n_j\{R\}$ are the numbers of failures and ruptures due to degradation mechanism j, T is a quantity of reactor operation experience in reactor-years.

The point estimates of failure frequencies $\lambda_j\{F\}$ and conditional probabilities $P_j\{R \mid F\}$ have been calculated based on data from Table 1 and are presented in Table 2. It should be mentioned that for degradation mechanisms like TF, SCC, COR there were no rupture events observed for $T = 891$ reactor years. In accordance with EPRI approach [3] for these degradation mechanisms the upper estimates were obtained for $P_j\{R \mid F\}$ in assumption of one rupture per T reactor years. The same assumption was made for calculation of $\lambda_j\{R\}$ estimates.

Table 2 - The estimates of failure and rupture frequencies

Degradation mechanism	Failures	Ruptures	Frequency per reactor year	Conditional rupture probability	Rupture frequency (per reactor year)	
	$nj\{F\}$	$nj\{R\}$	$\lambda_j\{F\}$	$P_j\{R \mid F\}$	$\lambda_j\{R\}$	
			Point estimate	Point estimate	Point estimate	Bayes' updated estimate
CF	7	2	$7.86*10^{-3}$	0.286	$2.24*10^{-3}$	$2.30*10^{-3}$
TF	4	-	$4.49*10^{-3}$	<0.250*	$<1.12*10^{-3*}$	$9.98*10^{-4}$
SCC	25	-	$2.81*10^{-2}$	<0.04*	$<1.12*10^{-2*}$	$9.98*10^{-4}$
COR	10	-	$1.12*10^{-2}$	<0.1*	$<1.12*10^{-3*}$	$9.98*10^{-4}$
WH	2	2	$2.24*10^{-3}$	1.000	$2.24*10^{-3}$	$2.23*10^{-3}$
FAC	62	14	$6.96*10^{-2}$	0.226	$1.57*10^{-2}$	$1.14*10^{-2}$
VF	43	10	$4.83*10^{-2}$	0.233	$1.12*10^{-2}$	$9.71*10^{-3}$
D&C	26	2	$2.91*10^{-2}$	0.077	$2.24*10^{-3}$	$2.30*10^{-3}$
OTH	2	1	$2.24*10^{-3}$	0.500	$1.12*10^{-3}$	$1.60*10^{-3}$
UNK	26	1	$2.92*10^{-2}$	0.038	$1.12*10^{-3}$	$1.60*10^{-3}$
TOTAL	207	32	0.232		$3.93*10^{-2}$	$3.67*10^{-2}$

* For the degradation mechanisms with no observed ruptures the upper value of point estimates are presented under an assumption of one rupture is observed per T reactor-years.

Several issues dealing with frequencies estimation in terms of point estimates are formulated in [3]. One of them is the uncertainties in the estimates that are not conveyed as point estimates provide a false appearance of accuracy. Another one is that only upper bounds of frequencies can be obtained if zero number of events is observed. To alleviate these problems in EPRI RIISI methodology the Bayes' approach is applied. Based on this approach point estimates must be updated using the information obtained from the sources other than in-service experience. In accordance with Bayes' approach the rupture frequencies are treated in terms of uncertainty distributions based on the information, prior to in-service experience.

For the calculation of Bayes' estimates of rupture frequencies the methodology from [5] was applied. Let us consider the random variable θ. We assume that distribution density $g(\theta)$ is known before any empirical data is collected. So, prior model is presented by $g(\theta)$. If empirical data is collected, the next step is to calculate an estimate of random variable θ having not only prior knowledge ($g(\theta)$), but also empirical data. We considered the random variable X depending on θ and x_i, $i = 1,...,n$ - observed values of X. The analysis of empirical data makes it possible to develop a sampling model $f(x \mid \theta)$, where $f(x \mid \theta)$ is conditional probability distribution density for variable X. More accurate posterior model can be developed based on collected empirical data. This model is described by posterior probability distribution density function $g(\theta \mid \vec{x})$ of parameter θ for the given empirical data $\vec{x} = (x_1,...,x_n)$. The relationship between prior and posterior models is defined by Bayes' theorem:

$$g(\theta \mid \vec{x}) = \frac{\left[\prod_{i=1}^{n} f(x_i \mid \theta)\right] g(\theta)}{\int \prod_{i=1}^{n} f(x_i \mid \theta) g(\theta) d\theta}, \tag{6}$$

For the quadratic loss function the Bayes' estimate $\hat{\theta}$ of variable θ is defined from the condition of posterior risk minimum:

$$M[(\theta - \hat{\theta})^2 \mid x] = \int (\theta - \hat{\theta})^2 g(\theta \mid x) d\theta \to \min, \tag{7}$$

where $M[(\theta - \hat{\theta})^2 \mid x]$ is a mathematical expectation of loss function for the parameter θ.
The following estimate is obtained from the condition (7) [5]:

$$\hat{\theta} = M[\theta \mid x] = \int \theta g(\theta \mid x) d\theta . \tag{8}$$

The estimates of pipe rupture frequencies due to different degradation mechanisms are defined using the above approach. The first step is to develop prior and sampling models. The sampling model is the probability distribution of random variable k, $k = 0,1,...,$, which is the number of ruptures per time period T under the condition that average rupture frequency λ is a constant. So, it is certainly correct if sampling model is presented by Poisson distribution:

$$f(k \mid \lambda) = \frac{e^{-\lambda t} (\lambda t)^k}{k!}, \ \lambda > 0, \ k = 0,1,..., \tag{9}$$

In EPRI methodology lognormal prior distribution of rupture frequency Λ is used. This prior distribution is assumed to be the same for all degradation mechanisms. If α and σ^2 are lognormal distributions parameters, the theoretical moments of the first and the second orders for the variable Λ are defined by the following expressions:

$$M\Lambda = e^{\alpha + \sigma^2/2}, \tag{10}$$

$$M\Lambda^2 = e^{2\alpha + 2\sigma^2}. \tag{11}$$

The parameters α and σ^2 can be expressed from (10) and (11) in the following way:

$$\alpha = 2\ln(M\Lambda) - \ln\left(D\Lambda + (M\Lambda)^2\right)/2, \tag{12}$$

$$\sigma^2 = \ln\left(D\Lambda + (M\Lambda)^2\right) - 2\ln(M\Lambda) \tag{13}$$

where $D\Lambda = M\Lambda^2 - (M\Lambda)^2$ - is a dispersion of random variable Λ.

Applying the method of moments, the theoretical moments can be estimated with the corresponding empirical moments below:

$$\hat{M}\Lambda = \frac{1}{n}\sum_{j=1}^{n}\lambda_j, \tag{14}$$

$$\hat{D}\Lambda = \frac{1}{n}\sum_{j=1}^{n}\left(\lambda_j - \hat{M}\Lambda\right)^2. \tag{15}$$

The estimates of lognormal distribution parameters α and σ^2 have been obtained using the point estimates of rupture frequencies due to different degradation mechanisms (Table 3). These estimates were used as λ_j in expressions (12-15). In such a way, the prior model, valid for all degradation mechanisms, has been developed. The obtained values of lognormal distribution parameters are $\hat{\alpha} = $-6.18304, $\hat{\sigma}^2 = 1.10769$ with the estimates of mean value $\hat{M}\Lambda = 3.591*10^{-3}$ and dispersion $\hat{D}\Lambda = 5.114*10^{-3}$, corresponding to the value $1.16566*10^{-2}$ for 0.95 confidence level quantile.

The moment estimation adequacy is presented at Fig. 1, where the solid line corresponds to the developed prior distribution and the squares correspond to the constancy intervals of empirical distribution function of discrete random variable. It can be concluded from Figure 1 that lognormal distribution gives an adequate prior model representation for rupture frequency.

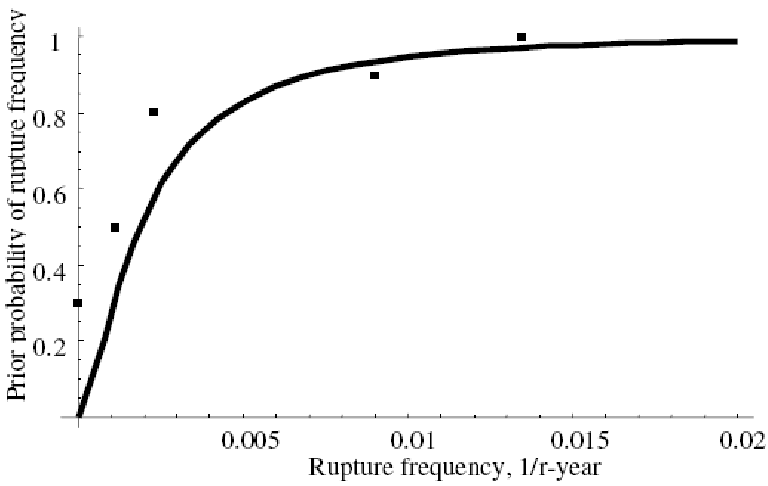

Figure 1 - Prior distribution of rupture frequency

If prior distribution density $p(\lambda)$ is known, one can find the posterior distribution density for degradation mechanism j. Applying the information that the number of ruptures due to degradation mechanism j is k_j, the posterior distribution density $p(\lambda \mid k_j)$ of rupture frequency due to degradation mechanism j can be expressed from (6) ($n = 1$) as:

$$p(\lambda \mid k_j) = \frac{\lambda^{k_j} e^{-\lambda t} p(\lambda)}{\int_0^\infty \lambda^{k_j} e^{-\lambda t} p(\lambda) d\lambda} \tag{16}$$

If prior distribution is the same for all degradation mechanisms, the posterior distribution is specific for each degradation mechanism.

Bayes' estimate $\hat{\lambda}_j$ of rupture frequency due to degradation mechanism j is calculated from the expression (17):

$$\hat{\lambda}_j = \frac{\int_0^\infty \lambda^{k_j+1} e^{-\lambda t} p(\lambda) d\lambda}{\int_0^\infty \lambda^{k_j} e^{-\lambda t} p(\lambda) d\lambda}, \tag{17}$$

Formulae (17) is valid for case $k_j > 0$.

If $k_j = 0$ another expression is used for calculations:

$$\hat{\lambda}_j = \frac{\int_0^\infty \lambda e^{-\lambda t} p(\lambda) d\lambda}{\int_0^\infty e^{-\lambda t} p(\lambda) d\lambda}. \tag{18}$$

The Bayes' estimates $\hat{\lambda}_j$ of rupture frequencies due to different degradation mechanisms were calculated using (17), (18) and obtained posterior distribution. The values of $\hat{\lambda}_j$ are presented in Table 2. The above approach makes it possible to estimate the rupture frequency due to degradation mechanisms for which no ruptures are observed (TF, SCC, COR). Note that in this case only upper estimate can be obtained using point estimation.
The estimation of rupture frequencies due to different degradation mechanisms is illustrated by Figure 2. Black color is used for the degradation mechanisms that can be identified under ISI program.

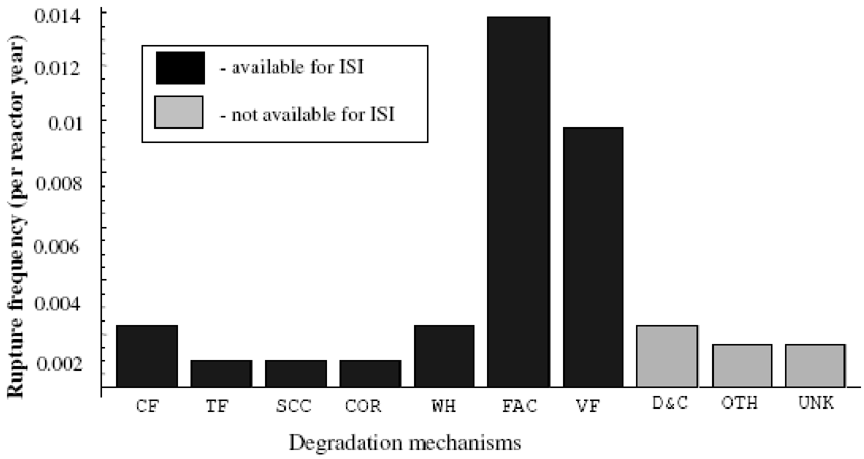

Figure 2 - Bayes' estimates of rupture frequencies for different degradation mechanisms

The prior and posterior rupture frequency distributions for FAC degradation mechanism (the highest number of observed ruptures) and for TF, SCC, COR degradation mechanisms (no ruptures observed) are presented in Figure 3. The curves of posterior distributions are different from each other. So, Bayes' updated model makes it possible to take into account the data, which is specific for each of degradation mechanisms. The same conclusion can be derived from Figure 4, where logarithmic scale is used for better clearness.

The obtained Bayes' estimates of rupture frequencies due to different degradation mechanisms are available to correct EPRI risk matrix on the base of VVER service experience. In accordance with EPRI approach [3] the high failure potential is given to the mechanisms with the order of rupture frequency equal or greater than 10^{-2} per reactor-year. From Table 2 it follows that high failure potential corresponds to FAC and VF degradation mechanisms. The other degradation mechanisms have the rupture frequencies with the order of value 10^{-3} or less. So, medium failure potential corresponds to all degradation mechanisms except FAC and VF. Low failure potential is given to piping segments with no degradation mechanisms. Risk matrix, which is developed using VVER service experience, is presented at Table 3.

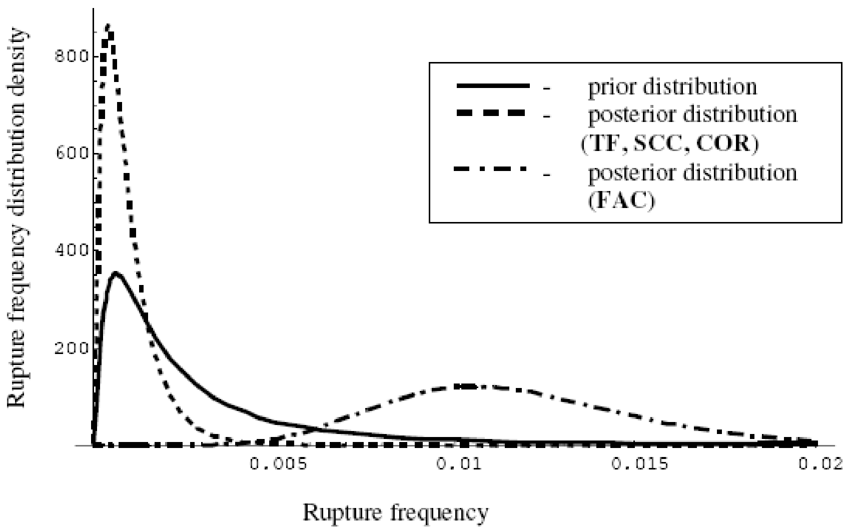

Figure 3 - Prior and posterior probability distribution for rupture frequency due to different degradation mechanisms

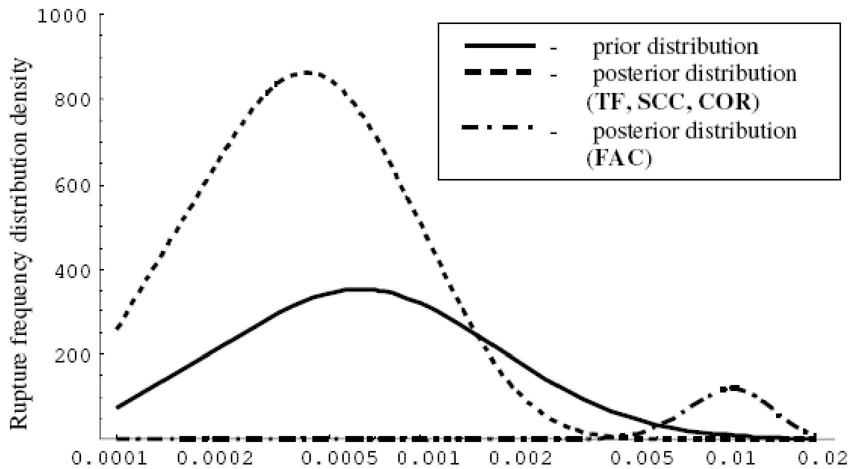

Figure 4 - Prior and posterior probability distribution for rupture frequency due to different degradation mechanisms (logarithmic scale)

Table 3 - Risk matrix

Degradation mechanism categories		Consequence categories			
		No	Low	Medium	High
		CCDP$<10^{-7}$	CCDP$<10^{-6}$	CCDP$<10^{-4}$	CCDP$>10^{-4}$
	High failure potential FAC, VF	Low category 7	Medium category 5	High category 3	High category 1
	Medium failure potential TF,CF, SCC, COR, E/C	Low category 7	Low category 6	Medium category 5	High category 2
	Low failure potential No degradation mechanisms	Low category 7	Low category 7	Low category 6	Medium category 4

4. APPLICATION OF EPRI RIISI METHODOLOGY FOR UKRAINIAN NPPS

EPRI RIISI methodology was applied for the re-evaluation of in-service inspection program for the piping of main feedwater system [6] of ZNPP unit 5 and RNNP unit 4. The failure consequences were evaluated using the results of Level 1 PSA analysis. In accordance with Level 1 PSA models all the pipes of main feedwater supply system is characterized by the common value of CCDP criterion:

Rivne NPP, unit 4: CCDP = $1.63*10^{-5}$.

Zaporizhzhya NPP, unit 5: CCDP = $4.81*10^{-4}$.

The system segmentation was carried out only based on degradation mechanisms criterion.

The pipe segments of main feedwater system of RNPP-4 and corresponding degradation mechanisms are presented in Table 4.

Table 4 - Pipe segments of RNPP-4 main feedwater system

Number of segment	Segment description	Possible degradation mechanisms
1.	Suction lines of main and supplementary feedwater pumps	SCC, COR, CF
2.	Pressure lines of main and supplementary feedwater pumps from pump jet nozzle to high-pressure feedwater heaters; bypass lines of high-pressure feedwater heaters	SCC, COR, CF
3.	Pressure lines from high-pressure feedwater heaters to the fitting RL61(62)S03	SCC, COR, CF
4.	Junction of high-pressure feedwater heater bypass lines D300 and high-pressure feedwater heater pressure lines near the fitting RL61(62)S03	TF, SCC, COR, CF
5.	Pressure line from the fitting RL61(62)S03 to steam generator level regulator manifold	SCC, COR, CF
6.	Steam generator level regulator manifold	SCC, COR, CF
7.	Feedwater pipelines from steam generator level regulator manifold to steam generators	SCC, COR, CF

The scope of ISI inspection for RNNP-4 main feedwater system piping segments was determined in accordance with EPRI RIISI methodology. The recommended scope of ISI program is presented in Table 5.

Table 5. Recommended scope of ISI program for RNNP-4 main feedwater system

Number of segment	Segment description	Risk category	Recommended amount of sampling
1.	Suction lines of main and supplementary feedwater pumps	Medium	10% elements
2.	Pressure lines of main and supplementary feedwater pumps from pump jet nozzle to high-pressure feedwater heaters; bypass lines of high-pressure feedwater heaters	Medium	10% elements
3.	Pressure lines from high-pressure feedwater heaters to the fitting RL61(62)S03	Medium	10% elements
4.	Junction of high-pressure feedwater heater bypass lines D300 and high-pressure feedwater heater pressure lines near the fitting RL61(62)S03	Medium	10% elements
5.	Pressure line from the fitting RL61(62)S03 to steam generator level regulator manifold	Medium	10% elements
6.	Steam generator level regulator manifold	Medium	10% elements
7.	Feedwater pipelines from steam generator level regulator manifold to steam generators	Medium	10% elements

The pipe segments of main feedwater system of ZNPP-5 and corresponding degradation mechanisms are presented at Table 6.

Table 6 - Pipe segments of ZNPP-5 main feedwater system

Number of segment	Segment description	Possible degradation mechanisms
1.	Suction lines of main and supplementary feedwater pumps	SCC, COR, CF
2.	Pressure lines of main and supplementary feedwater pumps from pump jet nozzle to high-pressure feedwater heaters; bypass lines of high-pressure feedwater heaters	SCC, COR, CF
3.	Pressure lines of supplementary feedwater pumps: the parts from throttling devices RL51(52)E01 to the weld joints of fitting	FAC, SCC, COR, CF
4.	Pressure lines from high-pressure feedwater heaters to the fitting RL61(62)S03	SCC, COR, CF
5.	Junction of high-pressure feedwater heater bypass lines D300 and high-pressure feedwater heater pressure lines near the fitting RL61(62)S03	TF, SCC, COR, CF
6.	Pressure line from the fitting RL61(62)S03 to steam generator level regulator manifold	SCC, COR, CF
7.	Steam generator level regulator manifold	SCC, COR, CF
8.	Feedwater pipelines from steam generator level regulator manifold to steam generators	SCC, COR, CF

The scope of inspection for ZNNP-5 main feedwater system piping segments is determined in accordance with EPRI RIISI methodology. The recommended scope of ISI program is presented in Table 7.

Table 7. Recommended scope of ISI program for ZNNP-5 main feedwater system

Number of segment	Segment description	Risk category	Recommended amount of sampling
1.	Suction lines of main and supplementary feedwater pumps	High	25% elements
2.	Pressure lines of main and supplementary feedwater pumps from pump jet nozzle to high-pressure feedwater heaters; bypass lines of high-pressure feedwater heaters	High	25% elements
3.	Pressure lines of supplementary feedwater pumps: the parts from throttling devices RL51(52)E01 to the weld joints of fitting	High	25% elements
4.	Pressure lines from high-pressure feedwater heaters to the fitting RL61(62)S03	High	25% elements
5.	Junction of high-pressure feedwater heater bypass lines Du300 and high-pressure feedwater heater pressure lines near the fitting RL61(62)S03	High	25% elements
6.	Pressure line from the fitting RL61(62)S03 to steam generator level regulator manifold	High	25% elements
7.	Steam generator level regulator manifold	High	25% elements
8.	Feedwater pipelines from steam generator level regulator manifold to steam generators	High	25% elements

5. CONCLUSIONS

The main results of our limited scope RI-ISI study are as follows:

1. EPRI RIISI methodology was found to be the most appropriate for the adaptation and optimization for Ukrainian NPPs in-service inspection. That is because of no special codes are required for EPRI methodology application.
2. For the adaptation of EPRI RIISI methodology the VVER-specific service experience has been analyzed. The data about failures of safety significant VVER piping has been collected. The Bayes' estimates of pipe rupture frequencies due to different degradation mechanisms have been obtained using an approach that expands EPRI methodology [3]. Risk matrix has been corrected using the Bayes' estimates.
3. In-service inspection programs for main feedwater system at Zaporizhzhya NPP, unit 5 and Rivne NPP, unit 4 have been revised using EPRI RIISI approach with corrected risk matrix. For RNPP unit 4 the 50% reduction of the number of inspections can be recommended within RIISI-based inspection program. However, for ZNPP unit 5 the 25% increase of the number of inspections can be recommended by RIISI-based inspection program. This is because the differences in PSA results: CCDP value for main feedwater system of ZNPP-5 is more than $1.0*10^{-4}$, so all the parts of the systems are of HIGH Risk Category and CCDP value for main feedwater system of RNPP-4 is more than $1.0*10^{-5}$ and less than $1.0*10^{-4}$, there is no potential for degradation mechanisms of HIGH risk category and all the parts of the systems are of MEDIUM risk category. From the other hand, Ukrainian PSA programs are still unfinished and the PSA results available are incomplete and do not correspond to nowadays requirements for risk-informed approach. The directions necessary for further implementation and optimization of RIISI methodology for Ukrainian NPPs are the following:
   - Ukrainian VVER NPPs pipe failure database development;
   - validation and application of structural reliability analysis computer codes, such as pc-PRAISE and SRRA WOG. Using of above codes makes it possible to evaluate the danger of degradation mechanisms not only based on analysis of in-service inspection data but also on the base of probabilistic fracture mechanics models;
   - validation and application of codes for flow acceleration corrosion (FAC) monitoring, such as CHECWORKS and KASEC. Development of common approach of FAC control for all Ukrainian NPPs;
   - improvement of Ukrainian NPPs PSA programs. More detailed PSA analysis makes it

possible to obtain CCDP criterion values not only for whole pipe systems but also for separate segments of the system. As a result, the RIISI-based inspection programs can be improved and become more accurate and adequate.

6. REFERENCES

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