# Risk Informed Approach to the In-Service Inspection Activities

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## 1 ABSTRACT

In the present paper, the aspects of Risk Informed In-Service Inspection (RI-ISI) are discussed.
Slovenian Nuclear Safety Administration (SNSA) and its authorized organization for the ISI activities, Institute of Metals and Technologies (IMT), are actually permanently involved in the ISI processes of the nuclear power plant (NPP) Krško. Based on the previous experience on the ISI activities, evaluation of the results and review of the existing practice in nuclear world, the activities are started to asses the piping of systems in the light of probability of failure. This is so called Risk Informed approach.
By the design established criteria, standards and practice gives good fundaments for the improvements implementation. Improvements can be done on the way that the more broad knowledge about safety important components of the systems shall bee added to the basic practice. It is necessary to identify conditions of the safety important components, such as realistic stress and fatigue conditions, material properties changes due aging processes, the temperature cycling effects, existing flaws characterization in the light of the previous detection and equipment technique used, assessment of the measurement accuracy on the results etc.
In addition to this deterministic approach, the principles of risk evaluation methods should be used. NPP Krško has, as practically majority of NPP's, probabilistic risk assessment (PRA) studies for all safety important systems and components. The methods and results from these studies can be efficiently used to upgrade classical deterministic results, based on which the in-service program as a whole is usually done.
In addition to the above mentioned, risk assessment and evaluation of the piping shall be done, which is not covered by the existing PRA analysis. To do this it is necessary to made risk evaluation of the piping segments, based on previous structural element probability assessment. Probabilistic risk assessment is important and one of the most powerful tools in the ISI optimization. Some basic work on the filed of the risk informed methods related to the nuclear safety components has been already done. Based on reference documentation, the most important steps in risk informed ISI are discussed: scope definition, consequence evaluation, failure probability estimation, risk evaluation, non-destructive examination method selection and possibilities of implementation, monitoring and feedback.
Recent experience on the ISI in the nuclear world shows that such practice plays strong role in the ISI decision making process and has some measurable effects too.
It is clear that classical criteria for the selection of ISI inspection locations are not completely in accordance with current measures of safety importance. Optimization shall give the operator of nuclear facility benefits on the resources and duration of the ISI inspections, on the other hand, the most important benefit for the nuclear safety administration shall be more effective control of the safety important components, aging management control and overall nuclear safety.

# 2 IN SERVICE INSPECTION BASIC PRINCIPLES

Main objective of In Service Inspection (ISI) is to permanently monitor the status of reactor coolant pressure boundary, including it's supports, joints and all elements that are important regarding nuclear safety. The ISI scope, methods and frequency is strictly prescribed, ussually by the appropriate standards and codes, based on the regulatory confirmed program. Slovenian Nuclear Safety Administration (SNSA) and it's authorized organisation for the ISI activities, Institute of Metals and Technologies (IMT), are actually permanently involved in the ISI processes of the nuclear power plant (NPP) Krško.

Generally, the purpose of ISI is to identify conditions and faults, that are service induced and may be precursors to failure of the pressure boundary of the primary reactor coolant system piping and related components. On the other hand, performing ISI activities, the licensee can indentify service induced degradation of pressure boundary and trough appropriate remedial activities can assure and maintain nuclear safety. The NPP Krško follows the ASME Boiler &Pressure Vessel Code, Section XI, which governs overall ISI activities. Reviewing the previous ISI reports, taking into account current approach in nuclear world, the process for ISI optimization started on the field of regulatory and professional practice. In addition, NPP Krško initiated some Plant life management activities.

NPP Krško has made Probabilistic Safety Assessment (PSA) studies (Level 1 and 2). The results of this studies can be used in the field of ISI too. Review of leading research projects on the ISI optimization in the world shows that all of them include PSA results. This is so called "Risk Informed Approach".

In PSA studies, the piping is not modeled regarding the probability of its failure. Only the elements in the certain pipeline, like valves, pumps, tanks etc. are treated on a probabilistic way. For the certain system of a safety important system, containing pipelines and other functional elements, introducing probabilistic fracture mechanics and failure probability of the elements, connecting the portions of pipeline, an overall global assessment of such system can be done. To optimise the existing ISI approach with the goal upgrading the safety measures to control the safety system, the ISI optimisation process shall started.

## 2.1 Inputs to the ISI optimisation process

Starting the ISI optimisation process, the following necessary steps has to be taken:

- Scope and ISI segments determination, subject to be optimized (taking into account piping safety class 1,2 or 3)
- Review of existing documentation related to previous ISI (findings,
- Review of design stress analysis reports for the systems to be optimised regarding ISI
- Operational loads in normal and transients conditions assessment
- Reevaluation of ageing effects
- Materials performance in the process environment
- Selection of the PSA segments to related to the ISI
- Assessment of the measurement equipment reliability

In addition to these initial steps, safety requirements and operability needs has to be taken into account. A clear decision has to be made early in the beginning and this is: to what level of optimization bring the overall ISI and which are the goals of such process. Economic effects of the optimisation are only one part of optimisation. Regarding nuclear safety, the most important is to achieve more deep knowledge about real condition of the systems and components.

## 2.2 Identification of failure consequences and assessment of failure potential

Failure consequences are obtained and assessed from PSA studies. They are classified as consequences from:

- Direct effects, due to the effects from, for example Loss of Coolant Accident, reactor scram, pressurized thermal shock, others
- Indirect effects, like earthquake, flooding, external fire, others

Assessment of failure potential has to be done for the piping segments, choosen system piping to be optimised, regarding following effects:

- **Thermal stratification**
- **High cycle fatigue**
- **Water hammer**
- **Fatigue**

Then, probability of failure of each segment is calculated by means of the probailistic fracture mechanics computer code, specially developet for such cases and containing so called “Risk Evaluation Spreadshits”. Categorization of piping segments regarding high or low safety significance is made by the expert panel evaluation method.

## 3 ISI INSPECTION LOCATIONS

Using the PSA Study results, the failure probability of piping segments can be assessed. In the cases, that is not possible, the use of other relevant data bases shall be used, like the industrial experience, databases of the similar installations and other sources. Effect of the failure of selected component segment shall be expressed in terms of failure probability, which then results with other failure probabilities in the “Core Damage Frequency” (CDF). On such way, the PSA assessment of the system segments should be used in reevaluation of CDF.

For described evaluation of system segments failure probability contribution to the CDF, there is necessary to have appropriate specific computer code tool. The input parameters to the computer code are usually:

- **Operating conditions and loads**
- **Material properties from the equipment vendor database**
- **Design limitations (stress, usage factor, other)**
- **Inspection methods reliability**
- **Most important, typical degradation mechanism**
- **Fatigue sensitivity regarding generic design values**
- **Defect growth rate estimation (fracture mechanics analyis results)**

Based on the engineering evaluation, usually the existing ISI program, following global locations for inspection are chosen:

- **Welds and heat affected zones on connecting parts of RCS piping to the components and associates safe ends (reactor pressure vessel, pressurizer, primary reactor coolant pump, steam generator)**
- **Supports and pipe whip restraints**
- **Bolted connections**
- **Other structural elements (snubbers, shims etc.)**

Detailed requests for the locations to be inspected are prescribed in Codes and standards, which are enforced to the licensee by the Regulatory Body.

To optimise location selection, licensee shall use the results of failure probability calculations, described above and compare them with existing selection. As the result, the correction of the locations which are subject of ISI examination can be done.

# 4 QUALIFICATION OF ISI METHODS

To optimize ISI process as a preparation for risk informed ISI introduction it is necessary to evaluate the ISI methods in the light of inspection performance, reliability and overall ability to perform their function. From the many pilot projects and "Round Robin" tests it was shown that in several cases that used ISI methods are not completely adequate, that means, adequate. Latest addenda to ASME Code Section XI react in several actions and consequently, international projects to assess the performance of ISI systems and to make technical justification of all relevant parameters entering ISI process. All mentioned results in so called qualification process

In the light of ISI systems optimisation, the group of following information shall be addressed:

- **Adequacy of parameters** like: component description, failure indication description, overall ISI parameters performance assessment
- **Inspection techniques and equipment** like: adequacy of probes, data acquisition and analysis system
- **Inspection procedures**: are they updated and validated
- **Role of new or improved technology**: is it appropriate to be implemented

As the result some significant changes can be achieved in ISI program. First of all, more realistic knowledge about all segments of ISI can be obtained. That means on one hand economic benefits, on the other improvement of the nuclear safety trough more realistic and specific problematic oriented ISI activities.

It can be concluded that proper qualification of ISI systems can be treated like significant optimisation of ISI system. It is foreseen that the qualification of ISI system will be done in the near future in the NPP Krško too. First steps of the above mentioned process are already done.

# 5 OPTIMISATION METODOLOGIES

Reviewing different approaches from organizations like EPRI, WOG, SKIFS, EDF and others it is clear that regarding ISI optimization prevails so called "Risk Based" approach. Their experience and main goals to be achieved will be of importance for ISI effectiveness. To select an adequate risk based methodology it is necessary early in the beginning to establish appropriate selection criteria. Usually, the following criteria were put forward: technical soundness, regulatory acceptance, economic effects and consistency with licensee plant programs.

From the operator point of view the ISI optimization programs are living programs and should be monitored continuously in order to account for changing conditions in the plant. Periodic updates are necessary, based on the inputs and changes resulting from plant modification/design changes, plant procedures, equipment performance, examination results and industry failure information.

Some pilot studies performed in different countries on a selected systems has been established in recent years. Comparison of selected methodologies has been performed and the working groups published theor conclusions and remarks. There are some common conclusions which are of practical importance for the countries which starts to begin optimization process:

- **ISI scope and components definition**: it is reasonable to divide the whole system into functional groups with the same consequence of failure
- **Failure consequence evaluation**: to address various failure modes and their consequence aspects
- **Degradation mechanisms**: use of quantitative and qualitative aspects, with use of operating experience
- **Risk evaluation**: categorization of segments in selected number of risk regions
- **Expert panel work**: additional validation of the categorized regions regarding safety significance Structural element selection: reevaluation of the existing structural elements selection regarding risk regions and safety significance

- **ISI program updates**: periodic update regarding changes in plant design, modifications and probabilistic analysis updates.

## 6 CONCLUSIONS

Optimisation of ISI activities with risk based approach to the piping segments can be treated as an improvement of nuclear safety. Slovenian Nuclear Safety administration and its authorized organization Institute of Metals and Technologies actively follow the progress on this field in nuclear world. Above mentioned ISI optimisation phases and milestones are under detailed evaluation in both organizations. First steps in this process are already done, that means, the scope of our activities has been determined. In addition, the reevaluation of previous ISI results started too. The main goal of this activity is to obtain clear, systematic database about status of the NPP Krško components and systems, which are subject of the ISI examination.

On the side of the licensee there some improvements on the field of ISI has been done too. Their ISI group is very well trained and has a lot of real, living experience. Their main efforts are oriented to new administrative requests regarding ASME XI and performing the third ten year period of ISI inspections. Both, regulators and ISI responsible persons from the power plant discuss frequently further actions, which are necessary. Recent important events that happened on the primary reactor coolant installations caused intensive research on different areas affecting ISI. It can be expected in near future that some optimisation suggestions will be issued relating optimisation of ISI from this side too.

Generally, existing ISI practice in Slovenia can be assessed as successful. There was no unacceptable findings in the structures and components and no corrective action was needed (with exception of degraded steam generator tubes, steam generators were replaced in year 2000). Currently used inspection techniques are modern and sensitive enough. More work is in front of us regarding the frequency of future inspections, locations to be inspected and in some special cases, the need for augmented inspection has to be evaluated.

Risk informed ISI optimisation process results in significant reducton of inspections. For example, a nuclear power plant, 4 loops PWR, can reduce the number of piping class 1 total inspections (volumetric and surface) by approximatly 60 to 70% and as a final result, the CDF can be reduced approximatly 1.6% to 2,5%.

Another area, not finally regulatory determined yet is the ISI Performance demonstration. On this topic the SNSA will need some help from the international projects, which are under progress. However, the current efforts to optimize ISI are under progress and all involved nuclear experts are aware about importance of this project. The common goal is to improve overall nuclear safety on a acceptable way, taking into account all available knowledge and experience.

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