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Development of Risk-Informed In-Service Inspection (RI-ISI) requirements at STUK

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1 ABSTRACT

Several risk-informed applications have been introduced since the beginning of 1990's in Finland. At the end of 1990's, STUK completed a pilot study which included, application of RI-ISI methods for Loviisa NPP and Olkiluoto NPP. The pilot study was conducted in full co-operation with licensees, Technical Research Centre of Finland (VTT) and regulatory body (STUK). Experience and insight gained from the pilot study were utilised in the development of risk-informed regulatory requirements.

In 2003, STUK issued updates for regulatory guides YVL 2.8 and 3.8 [1, 2] which set forth regulatory requirements on risk-informed in-service inspection (RI-ISI) applications. RI-ISI scope covers all plant systems and safety classes, including non-nuclear. The scope includes bellows, seals, hoses, small instrument pipes, etc. STUK requires that RI-ISI applications include expert panel which turned out valuable already in the pilot study.

In 2007, Loviisa finished full-scope RI-ISI application, which covered all systems in the plant. As a result of this application, new risk-informed in-service inspection program was implemented for Loviisa 1 in 2008. The new inspection program contains significant differences compared to the previous program.

TVO is supposed to finish RI-ISI application for Olkiluoto 1 NPP, in 2009 and for OL2 and 3, in 2010 and 2011. Olkiluoto 3 may be the first NPP unit implementing risk-informed pre-service inspection program. This is a challenge because no detailed international standards are yet available for pre-service inspection of NPPs.

Methods used in Finland for RI-ISI applications follow ASME Code, Section XI Appendix R. In addition, the insights of ENIQ Report nr. 23,"European Framework Document for Risk-informed In-service Inspection" have been utilised.

In Finland, oversight and operation of nuclear facilities is becoming increasingly risk-informed. As part of this, plant-wide risk-informed inspection programs are used in Finnish nuclear power plants. Full-scope RI-ISI programs require that the underlying PRA covers all operating states and initiating events and includes the risks of possible transitions between operating states with impaired systems.

2 INTRODUCTION

A pilot study dealing with PRA support to the development of the regulatory requirements was initiated at STUK late 1998. The aim of the project was to explore how the plant specific PRAs could best be utilised in the selection of in-service inspection (ISI) targets. The study on risk-informed ISI was aimed to consolidate the use of PRA in the present regulatory process and plant safety management. The target of the study was also to provide utilities with guidance on acceptable approaches to apply risk-informed ISI method. In addition, STUK obtained experience to support the review the licensee´s RI- ISI programs in the future.

The systems included in the study were the high pressure injection system and the emergency feed water system at Loviisa NPP, and the shutdown cooling system and the service water system at Olkiluoto NPP. The Finnish licencees contributed to the study by providing STUK with the qualified systems information data. As a consequence of the pilot study on RI- ISI, the regulatory guide YVL2.8 “Probabilistic safety analysis in safety management of nuclear power plants” [1] (issued in 2003) set forth a new requirement such that RI-ISI methods are mandatory while working up the ISI programs both for operating NPPs and new designs. The ASME Section XI related code cases and ENIQ`s (European Network for Inspection and Qualification) development work on RI-ISI and qualification practices [3, 4, 12, 15] provided a well established basis for RI-ISI application. The Finnish licensees Fortum Power and Heat and TVO have conducted RI-ISI applications for operating plant units. RI-ISI approach is also used in the context of the on-going OL 3 EPR project.

3 PILOT STUDY ON RI-ISI

As a part of the further development of regulatory requirements, STUK conducted a pilot study on risk-informed in service inspection (RI-ISI) in co-operation with the licensees and the Technical Research Centre of Finland (VTT), in 1998-1999. The pilot study included two safety systems both from Loviisa (VVER-440) and Olkiluoto (BWR) NPPs [6]. The study produced essential insights of the applied method. Furthermore, the study gave guidance to extract items for further development. Based on these results and overall experience the general suitability of the method for further applications is evaluated.

STUK’s risk-informed procedure (EPRI method) [5,7] combines both the plant specific PRA information and the traditional insights in support of the system specific detailed in-service inspection program planning.

The procedure includes several steps such as the selection of the systems, consequence evaluation, qualitative degradation mechanism evaluation of piping and the division of the pipe segments into different inspection categories. Division of pipe segments into degradation categories is based mainly on qualitative identification of the mechanisms, which the pipe segments are exposed to. The division of the pipe segments into consequence categories is based on conditional core damage probability derived for plant specific PRA.

Finally, the expert panel (ASME Code, Section XI Appendix R, Method A) containing all related engineering disciplines combines the deterministic and probabilistic information as emphasized by the EPRI's approach and the NRC regulatory guides [8]. The pipe segments are divided into different inspection categories containing high, medium and low risk segments.

The expert panel discussion is a procedure to evaluate knowledge based uncertainties which might seriously undermine the decision making process. The panel combines deterministic and probabilistic information including

- information from risk ranking
- generic risk insights
- insights regarding external events and shutdown operations not included in the PSA scope
- appropriate deterministic restrictions

The experts in the panel represent extensive areas of operational and safety disciplines such as plant design, operation, maintenance, structural and material engineering, probabilistic risk assessment and in-service inspection. The panel itself can be seen both as quality assurance or critical review of the preliminary results and as a support for the decision making for the final categorisation of the pipe segments.

The aim of the panel discussions in the study was not to determine a proposal of the final in-service inspection program for a plant unit but to assess the capability of the RI-ISI method to effect the inservice inspection applications.

3.1 Preparation of data

The pilot method was applied to systems (a) whose in-service inspection programmes are included in the present ASME programme (b) whose in-service inspection programmes are not included. The high pressure injection system at the PWR and the shutdown cooling system at the BWR plant are included in the present deterministic ASME programme. In contrast, the emergency feed water system (PWR) and the service water system (BWR) are not included in the present deterministic ASME programme. However, these systems are included in the inspection programme that is based on the utility-specific requirements and references originating from their own operating experiences and feedback.

A step of a great importance for the whole assessment is the collection of information of current inspection programmes, including ASME XI programmes for plant systems, information on plant walk through documents, isometric and installation drawings (system, pipe etc) and process drawings. The insights received from the plant walk through and think through analysis give an important ingredient to the risk-informed ISI study. It is essential that the preparation work has been performed with high quality in order to carry out a qualified decision making process for demonstrating the need for ISI changes. In addition, accurate documentation guarantees repeatable process that achieves identical results in the future if necessary.

The processing of the technical information was conducted following the guidelines given by the panel experts. The aim of the process was to prepare the wide range of information into a compact form to be readily utilised by the experts.

The initial divisions of the pipe runs into segments were based on Failure Mode and Effect Analysis including both qualitative degradation mechanism evaluation and consequence evaluation. The preliminary segmentation resulted into 28 segments for the shutdown cooling system, seven segments for the service water system (BWR) and 10 segments for the emergency feed water system and six segments for the high pressure injection system (PWR).

4 DEVELOPMENT OF REGULATORY REQUIREMENTS ON RI-ISI

The pilot study gave experience, insight and incentive for further development of risk-informed regulatory requirements. Accordingly, STUK issued updates for regulatory guides YVL 2.8 and 3.8, which set forth a new requirement such that RI-ISI methods are mandatory while drawing up the ISI programs both for operating NPPs and new designs.

The new requirement included a principle such that RI-ISI scope shall cover all plant systems and safety classes, including non-nuclear. The scope includes bellows, seals, hoses, small instrument pipes, etc. Further, the requirement set forth that RI-ISI applications include expert panel which turned out valuable already in the pilot study. In addition, emphasis shall be focused on means to reduce radiation doses received during inspections.

According to STUK experience, risk related to change of operating state may be significant and has to be taken into account if pipe rupture causes shutdown or if repair of the rupture requires shutdown. In these cases the plant is shut down with impaired systems. The full spectrum of operating states has to be taken into account. For example in the Loviisa NPP, the most significant risk for some pipe segments is due to ruptures in shutdown states.

Methods used for RI-ISI applications follow ASME Code, Section XI Appendix R. Also recommendations of ENIQ Report nr. 23, ”European Framework Document for Risk-informed In-service Inspection” and work on qualification practices provide a well established basis for RI-ISI application [14, 12, 15] .

5 LOVIISA RI-ISI APPLICATION

In Loviisa NPP RI-ISI application, the system specific risk assessments are based on the Loviisa full scope level 1 and 2 PRA model and the failure consequences (indirect effects from pipe failures) to other systems are considered as they are taken into account in the PRA model. The existing full scope PRA model was detailed enough for RI-ISI, because the consequences of different kinds of leakages were studied in the flood and internal event PRA. Accordingly the first screening and selection of the piping segments was made on the basis of the existing full scope PRA. The flooding analysis includes leakages in large areas causing an initiating event and also failing safety components that would be needed in case of such an initiating event. The internal events include small leakages, water and steam jets that can cause localized wetting of single electric equipment. A systematic identification and mapping of flood sources and spreading routes as well as equipment vulnerabilities to external effects has been done in the PRA. As required, side effects of increased temperature and humidity have been analyzed in the PRA.

Systems and piping segments, in which pipe ruptures could result in a core damage probability larger than 10^{-6} or a large early release probability larger than 10^{-7} are selected for further studies. The other systems and piping, which had small effect on the core damage risk, are screened out.

The consequence assessment is based on the Conditional Core Damage Probability (CCDP) and Conditional Large Release Probability (CLRP) derived from the Loviisa full scope level 1 and 2 PRA. The failure assessment is performed on a qualitative basis by group of in-house experts familiar with Loviisa NPP associated materials integrity and in-service activities. Pipe segments that exceed the screening level are divided into three categories on the basis of their CCDP or CLRP values:

low: $10^{-6} \leq \text{CCDP} < 10^{-5}$,

medium: $10^{-5} \leq \text{CCDP} < 10^{-4}$ and

high: $\text{CCDP} \geq 10^{-4}$.

The high limit value was selected to be the same as in the ASME Section XI Supplement R. The CLRP limits are one order of magnitude lower than the CCDP limits.

At the VVER-440 Loviisa Unit 1, the existing ISI program for 10 year period 1998 -2007 was based on the ASME Code Section XI. The Loviisa pilot application of risk-informed in-service inspection methodology was initiated in the spring, 2005. In the pilot application, two systems, one primary and one secondary system were considered. A plan for utilising the risk informed methodology for Loviisa Unit 1 piping was submitted to the Radiation and Nuclear Safety Authority (STUK) for review and approval in 2005. STUK accepted the plan in 2006.

In the Loviisa RI-ISI application, the risk assessment is applied for the whole unit, i.e., for safety classes 1, 2, 3, 4 as well as for non nuclear safety class classified piping [11]. The risk-informed selection process as described in ASME Code, Section XI, Nonmandatory Appendix R, Supplement 2, Method B was chosen as a basic approach for the new ISI program.

An independent expert panel evaluates all selected systems and reviews the basis of the risk classification in order to guarantee that the final RI-ISI program will be planned in a proper way.

In 2007, Loviisa completed the full-scope RI-ISI study, which included all systems in the plant. The risk-informed in-service inspection program was introduced for Loviisa 1, in 2008. Significant differences were implemented compared to old inspection program.

5.1 Results

The number of inspections was almost doubled at Loviisa 1 unit due to RI-ISI approach compared with the deterministic approach. This is quite an extraordinary result because in previous RI-ISI applications, the number of inspections has significally reduced. The explanation to the increased number of inspections is that RI-ISI method was applied to pipings of all safety classes i.e. 1,2,3,4 and non-nuclear whereas the earlier ASME Code, Section XI focused on safety classes 1 and 2. In addition, opposite to the deterministic approach, the RI-ISI approach does not exclude small diameter pipings from the inspection program. Therefore, small size temperature measurement nozzles and pressure measurement piping as a significant contributor to risk are introduced as new targets in the ISI program.

Considering the total number of inspections, the RI-ISI approach changed the gravity point of inspections. Accordingly, the main focus of inspections was moved from the safety class 1 and 2 to safety classes 3, 4 and non -nuclear class pipings. As an example the number of inspections in the main coolant piping reduced from approximately 150 to 50. The number of inspections in various safety class systems do not necessarily reflect the actual cost and resources required for in-service testing, since the testing methods, test intervals and test qualification process may vary significantly between safety classess. The selection of structural elements for inspection of the new Risk-Informed ISI program was completed by the end of 2008.

6 DEVELOPMENT OF REQUIREMENTS FOR LICENSING OF NEW NPP DESIGNS

The Finnish regulatory guides require that the applicant for an operating licence for a new NPP submits to STUK several risk informed applications, including the risk-informed programs of the Technical Specifications, in-service testing, on-line preventive maintenance and in-service inspections.

While drawing up the risk informed inspection program, the systems of classes 1,2,3,4 and non nuclear must be regarded as a whole. Combining the information from PRA and the degradation mechanisms of pipes and the secondary impacts of pipe ruptures, the inspections are focused on those pipes whose risk significance is greatest. Similarly, the reduction of radiation doses shall be optimised by focusing on inspections and optimising inspection periods.

Acceptable RI-ISI methods are described in a standard, ASME Code, Section XI Nonmandatory Appendix R [14]. Acceptable application guidelines are given in a European Union report, ENIQ Report nr23. European Framework Document for Risk-informed In-service Inspection” [12].

While drawing up the risk-informed inservice inspection program, the results must be evaluated by an expert panel. In addition to power operation, low power and shut down states and the transition between them shall be considered in the RI-ISI approach. While determining the degradation class the fatigue, stress corrosion and erosion corrosion must be regarded as degradation mechanisms. Water hammer and other exceptional loading situations must also be regarded (ASME Code, Section XI, "Non-mandatory Appendix R, Risk-informed Inspection Requirements for Piping, Table R-S2-1, Degradation Mechanisms). If application of LBB criterion is claimed, adequate leak detection system is required.

If computer programs of structural reliability (SRM-codes) [13] are used for estimating the failure probability of piping, the results must be evaluated by expert judgement methods. The incompleteness and possible unanticipated and unknown degradation mechanisms associated with RI-ISI methods must be taken into account in the uncertainty analysis. Uncertainty analyses must be used in context of expert judgements and SRM codes. Screening of very small failure frequencies is unacceptable if the consequences of failures are severe. Such situations must be regarded on a case by case basis. In such cases the uncertainty analyses are of importance.

The qualification of NDT methods aimed at ensuring the integrity (levels of qualification) must be evaluated by risk-informed methods and the uncertainty associated with the NDT inspections must be taken into account as well. While drawing up a risk- informed inservice inspection program for new designs without earlier inspection program, the risk resulted from pipe failures must be used as the basis for the selection of structural elements for inspection. Pre-service inspections (PSI) must be utilized while drawing up the risk-informed inservice inspection program.

While drawing up the risk-informed in-service inspection program, the traceability of selection of the structural elements for inspection must be ensured with a detailed documentation. A part of the risk informed inspection program is a numerical comparison of risk between the preceding and present inspection program. To be acceptable, the risk from new inspection program must be smaller than the risk from the preceding program. Because the RI-ISI program is a living document the objectives of the program shall be evaluated periodically and the program updated regularly.

Olkiluoto 3 may be the first NPP unit implementing risk-informed pre-service inspection program. No detailed international standards are yet available for pre-service inspection of NPPs.

7 CONCLUSIONS

In Finland, oversight and operation of nuclear facilities is becoming increasingly risk-informed. As part of this, plant-wide risk-informed inspection programs are used in Finnish nuclear power plants. Full-scope RI-ISI programs require that the underlying PRA covers all operating states and initiating events and includes the risks of transitions between operating states with impaired systems.

According to the experience received, risk related to change of operating state may be remarkable and has to be taken into account if pipe rupture causes shutdown or if repair of the rupture requires shutdown. In these cases the plant is shut down with impaired systems. The full spectrum of operating states has to be taken into account.

The RI-ISI approach seems to change the gravity point of inspections. In terms of the number of inspections, the main focus is from the safety class 1 and 2 to safety classes 3, 4 and non -nuclear class pipings. As an example the number of inspections in the main coolant piping reduced at Loviisa plant to one third from that of the preceding program.

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