NUGENIA
Nuclear Generation II&III Alliance

ENIQ Position on

Safety Benefits of Risk-Informed In-Service Inspection

ENIQ Report No. 70

January 2024

ENIQ
European Network for Inspection & Qualification
NUGENIA Technical Area 8

ENIQ
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This document was prepared by the SNETP Association.

Brussels: The SNETP Association

ISBN 978-2-919313-39-6 (pdf)

ISBN 978-2-919313-39-6 (print)

Executive Summary

This Position Paper has been developed as a consensus document amongst the members of NUGENIA Technical Area 8 (TA8) – European Network for Inspection and Qualification (ENIQ), and specifically the Sub-Area Inspection Effectiveness (SAE). It outlines the philosophy of the Risk-Informed approach to inspection planning and the inherent safety benefits of adopting such an approach. Risk-informed In-Service Inspection offers several advantages over conventional deterministic programmes. The benefits of Risk-informed In-Service Inspection are described in this report and supported by evidence from world-wide applications.

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1. Introduction

Nuclear Power Plant (NPP) operators and nuclear regulators are often tasked with managing a set of competing demands with a finite pool of resources. These demands include a continuous focus on plant and personnel safety, operational practices, plant reliability and process efficiencies. This report demonstrates how safety can be improved by adopting Risk-Informed (RI) methods to develop In-Service Inspection (ISI) programmes and practices more effectively.

Based upon over 60 years of operating experience, the nuclear industry and its regulators have gained improved knowledge and understanding of the mechanisms of plant degradation and the locations within the NPP that are most susceptible. This knowledge base when combined with a RI decision-making logic can be used to identify locations for ISI on a more informed and targeted basis than more traditional deterministic schemes.

This report presents a summary of the safety benefits of adopting a RI approach to ISI site selection and the advantages over traditional deterministic approaches. Real world examples are presented which demonstrate tangible benefits to plant and personnel safety that have resulted from the application of risk-informed in-service inspection (RI-ISI).

2. The Purpose of ISI

The design, materials, and operation of a NPP are selected to ensure the absence of degradation mechanisms and to provide safe and continuous operation throughout its operational life. However, the judgement that there are no active degradation mechanisms is based on an understanding of the causes of degradation initiation and progression, as well as the conditions within the NPP throughout its lifetime (e.g., transient loadings, thermal and hydraulic conditions). All these factors affect the level of confidence in the avoidance of degradation and each factor has an associated level of uncertainty which may change over time. Inevitably, there will always be a level of residual risk that unexpected degradation could occur at some point in the future.

ISI addresses this through:

- Detection of flaws that could affect the safety of the component or plant,
- Verifying that design assumptions are correct and are applicable through-out the plant lifetime, and in doing so provide an element of defence-in-depth (DiD).

Both RI and deterministic approaches to ISI site selection provide a means of reducing the level of residual risk and providing DiD. However, RI and deterministic schemes differ in several crucial aspects in so far as RI is explicitly focused on the consequence of failure and failure potential coupled with a flexibility that allows practical factors such as worker dose and outage complexity to be managed effectively without compromise to minimising the residual risk. Deterministic schemes tend to be less flexible and can lead to ISI of sites that do not contribute to reducing the residual risk in an effective manner.

3. Historical Perspective

At the beginning of many of the nuclear build programmes during the 1950s and 1960s there were no prescribed means of inspecting NPPs through-life. The design philosophy applied to plants did not include any expectation that ISI would be needed and the technologies that could facilitate meaningful examination for cracking, principally ultrasonic examination, were relatively immature.

As operational experience was gained there was an increasing awareness that degradation mechanisms could be active despite careful plant design and material selection. This realisation led to the idea of inspecting through-life to provide confidence in through-life component behaviour and to contribute to overall nuclear safety. Deterministic ISI codes were developed from the consideration of the following factors:

- Inspection sites selected through engineering judgement (locations of high stress; transition welds etc.),
- Fatigue crack initiation,
- Extent of inspection dependent upon safety class,
- Ultrasonic examination being the only available practical method to effectively inspect component inner surfaces,
- Inspection sensitivities and reporting criteria prescribed within the inspection code based on experience.

However, during the 1970s and 1980s a series of round-robin exercises (PISC I-II; DDT) [1][2][3] undermined confidence in the reliability of ultrasonic inspection. The results from the inspection teams were unacceptable in their variability when designed against the requirements of a prescriptive code. This realisation led directly to the development of protocols for inspection system qualification:

- European Network for Inspection and Qualification (ENIQ) and the development of the ENIQ Qualification Methodology [4] – widely applied in lieu of Performance Demonstration within Europe.
- ASME XI Division 1 [5] Appendix VIII for 'Performance Demonstration' – widely applied outside of Europe.

Many years' experience of operating NPPs is now available which has resulted in improved knowledge of the mechanisms of plant degradation and the locations within the plant that are most susceptible. Improved probabilistic safety assessments have increased the understanding of the safety significance of individual components in terms of the consequences of their failure. These developments led the nuclear industry to consider setting inspection priorities based on risk.

The principle of RI-ISI has been developed and methodologies have been established that are in use worldwide. ENIQ has developed several related documents including the European Risk-Informed Framework Document [6].

3.1. Deterministic ISI Practice

Deterministic ISI codes typically base ISI requirements for passive components on prescriptive codified practices supported by regulatory oversight of the requirements, which may be augmented to address specific issues. These codes specify the locations, frequency and methods of inspection based primarily on the type and safety class of the component. The philosophy of the inspection codes is to address the threats to integrity based on a limited number of design safety classes.

Deterministic design codes define a hierarchy of component classes. For example, ASME Section III [7] defines safety Classes 1, 2 and 3. The alignment between safety classes and the classes within design codes is dependent on the safety classification methodology applied in the relevant country:

- Primary circuit components, such as major pressure vessels and pipework systems, making up the coolant pressure boundary would typically be Class 1.
- Major safety systems, such as high-pressure safety injection systems, whose function is required to avoid core failure in the event of a pressure boundary failure would be assigned Class 1.
- Components and systems with degrees of isolation or within the make-up capacity of plant systems during normal operation are likely to be Class 2 or 3.

Within a deterministic scheme, the sites which receive ISI are closely linked to the safety classification.

The scope of the degradation mechanisms considered is limited to those identified within the original design basis of the code. As new degradation mechanisms have emerged since the creation of the deterministic codes, additional augmented inspection programmes have been introduced (e.g., Primary Water Stress Corrosion Cracking (PWSCC), Microbiologically induced corrosion (MIC), Flow Accelerated Corrosion (FAC)).

In summary, the application of the classification-led approach adopted within deterministic codes leads to a focusing of attention and resources on the higher classified components (e.g., Class 1). In broad terms, the closer the component is to the Reactor Pressure Vessel (RPV), then the higher the classification (Class 1). The allocation of design, inspection and testing resources, including ISI, being a function of the safety classification process.

3.2. Inspection Reliability

The capability and reliability of the applied non-destructive testing (NDT) system to detect the degradation mechanism(s) of concern are important to the overall effectiveness of an ISI programme and the level of residual risk.

The application of RI-ISI requires an explicit consideration of all foreseeable degradation mechanisms. This aspect facilitates more effective targeting of inspection methods than deterministic approaches which typically adopt a more generic approach being primarily focused on fatigue cracking. The requirements commonly employed for the demonstration of inspection capability and reliability as part of deterministic ISI codes (Inspection Qualification/Performance Demonstration) are readily transferable to RI methods.

3.3. Risk-Informed ISI Practice

RI-ISI aims at a rational plant safety management programme informed by the results of plant-specific risk analyses. The fundamental principle is to identify high-risk locations where the inspection efforts should be concentrated and to provide an on-going improvement in the overall plant safety together with reduced radiation doses for the inspection personnel.

This position reflects developments in Probabilistic Safety Assessment (PSA), the understanding of degradation mechanisms (e.g., root cause evaluations, structural reliability modelling) and the experience gained from many reactors operating years. The European Risk-Informed Framework Document [6] provides details of the RI-ISI process.

Typically, the consequence of failure at a location is estimated from the plant PSA in terms of either Conditional Core Damage Probability (CCDP) or Conditional Large Early Release Probability (CLERP) which is then combined with the Probability of Failure (POF) at that location to provide a risk value. The POF may be assessed by use of modelling, expert judgements, or statistics, depending on the degradation mechanism, service experience and available information. From this process a risk-ranking can be produced, and the higher risk location used to inform ISI site selection. It should be noted that many times the risk-ranking alone does not define the final ISI site selection as consideration of inspection access, worker exposure and outage complexity can impact the final inspection element selection.

RI-ISI schemes can be readily tailored to reflect individual NPP conditions, operation, and potential degradation mechanisms. As such, this provides flexibility to select ISI locations that manage the residual risk effectively but consider other important factors such as worker dose, cost, and outage complexity.

While RI-ISI methodologies have been incorporated into codes and standards in a number of countries (for example, ASME and CSA), it is often the case that each plant-specific implementation will still require its own regulatory review and approval. In some countries the regulator has issued regulatory guidance for implementing RI-programmes (for example, Regulatory Guide 1.178 in the U.S.) while in other countries the specific regulation has been updated (for example, YVL E.5 in Finland [8]). Further, in 2004 the Nuclear Regulators Working Group (NRWG)[1] published a report *'Report on the Regulatory Experience of Risk-Informed Inservice Inspection of Nuclear Power Plant Components and Common Views'* [9]. The objective of the NRWG report was to analyse from the regulatory point of view key aspects associated with the application of RI-ISI, and to present a series of recommendations of good practices or common positions reached by the regulators represented in the Task Force.

4. Principal Safety Improvements through RI-ISI

4.1. Risk Reduction

The most evident safety benefit comes from the very fundamental idea of RI-ISI:

> ***To reduce plant risk by identifying with the help of PSA the safety significant locations and allocating inspection effort and resource accordingly.***

The greatest safety benefit is achieved with a full-scope RI-ISI, where ISI sites are often relocated from higher Class locations (sometimes 1 and 2) to lower Classes (3 and 4) and there is a demonstrable reduction in overall plant risk. This facilitates a plant specific ISI programme reflective of the risk profile. In addition to the improved targeting of ISI, a plant specific risk analysis also provides the opportunity for a more holistic approach to improving plant safety by other means than ISI. These are related to physical changes to the plant, improvements in inspection focus/application, reductions in worker exposure, outage management and personnel safety and are shown graphically in Figure 1.

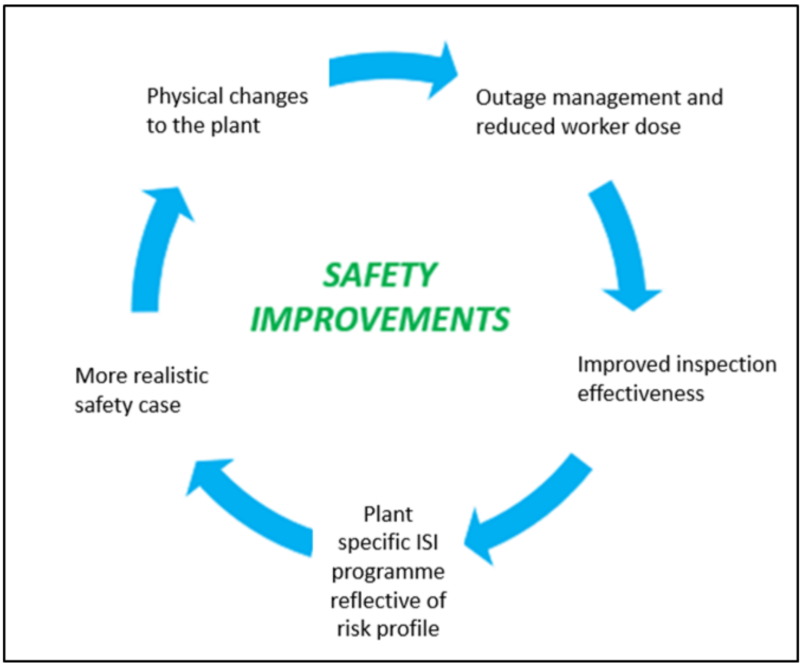

Figure 1. Safety improvement from RI-ISI.

[1] The Nuclear Regulators' Working Group (NRWG) is an advisory expert group to the European Commission and is made up of representatives from safety regulatory authorities and technical support organisations from EU member countries and, in anticipation of their accession to the EU, representatives from candidate countries. Switzerland participates as an observer.

4.2. Physical Changes to the Plant

From a safety and resource perspective, the primary goal of developing a RI-ISI programme is an optimized ISI programme. However, experience has shown that changes to plant layout and design may be a more effective safety management tool than inspection (in the form of NDT). Such an approach often applies to low safety class systems that would not require inspection under deterministic rules, but the failure of which would lead to more safety significant secondary consequences.

The RI-ISI approach requires a plant specific risk analysis which provides a detailed understanding of piping system failure modes, including both direct effects and the risk associated with internal hazards created via the piping failure and consequential secondary effects on other systems (for instance, flooding or jet impingement). There are several examples where plants have removed the risk associated with internal hazards. In such situations, plant modifications and removal of the hazard are a better alternative to inspection (for example, such as relocation of low safety class piping from a plant area that contained equipment important to safety).

Another example is the installation of a flow restricting orifice in a portion of the fire protection system. In this case the challenge was to minimize the impact of postulated failure of fire protection piping systems while still providing the capability of the fire protection piping to provide its intended function (fire suppression).

4.3. Inspection Focus and Effectiveness

Many deterministic ISI programmes have rigidly defined examination volumes and techniques that link back to the original design basis of the code. Service experience has shown that the assumptions made within codes are not always representative of the degradation mechanisms that dominate piping reliability. In contrast, RI inspection planning identifies the relevant degradation mechanism and location, and appropriate and effective inspection techniques are selected.

4.3.1. Surface Examination under Deterministic Rules

In the case shown in Figure 2, the deterministic examination requirement in accordance with ASME Section XI Division 1 is to conduct a surface examination on the outside diameter of the pipe. However, experience has shown that most piping degradation begins on the inside surface and, as such, the deterministic based examination will only identify piping degradation if the crack has grown through wall which is obviously too late to prevent the failure of the pressure retaining function.

While in the case of a RI-ISI programme, identification of the dominant degradation mechanism is inherent in the process, which then drives selection of the most appropriate examination volume/surface and examination technique(s). In the case of degradation that attacks the inside diameter a volumetric examination would be required (typically ultrasonics), which inspects the inside volume of the wall thickness where degradation is most likely to initiate and grow.

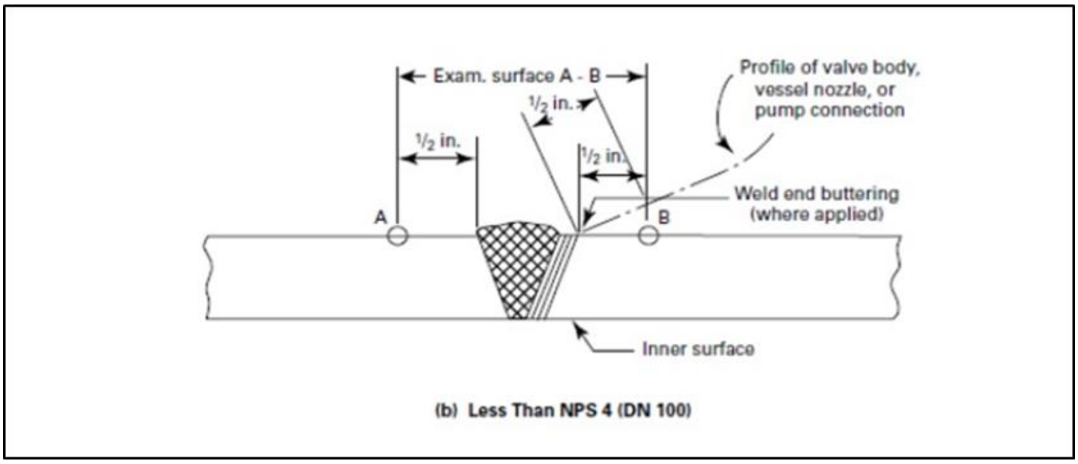

Figure 2. Example of NDE requirements for outside surface examination, while cracking usually occurs at the inside. (© EPRI)

4.3.2. Inspection for Cause

The examination volume depicted in Figure 3 by the red lined box is typical for a deterministically defined ISI programme and is focused on the weld and a small portion of the weld heat affected zone (HAZ). Operating experience has shown that for some situations degradation initiates at the counterbore region and therefore significant cracking can occur and not be detected when using the deterministically defined examination volume. The deterministic design code requirements can be too general in nature, slow to evolve based on service experience, and can produce requirements that are not fit-for-purpose.

In contrast, RI-ISI methods allow a focused review of relevant degradation mechanisms and in-service experience and tailoring of requirements. In this example, a better understanding of the degradation mechanism results in an extension of the examination volume to capture the applicable counterbore region for applicable combinations of susceptible degradation mechanism and joint configuration.

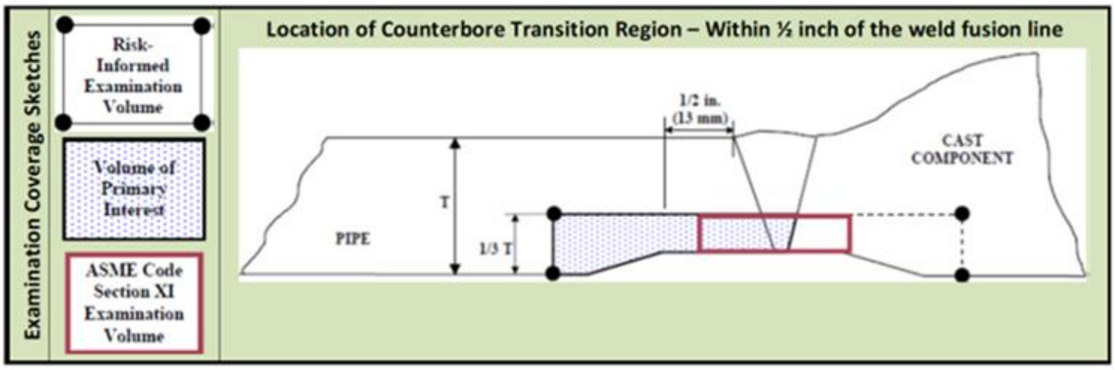

Figure 3. Example of inspection for cause. (© EPRI)

4.4. Reduced Worker Dose and Waste Material

Typically, deterministic ISI requirements are focused on the higher classes of system such as safety related Class 1 or Class 2 using a standard such as ANS-51.1 [10] or ANS-51.2 [11]. For Class 1 systems and a large number of Class 2 locations the dose to the worker and support staff in conducting these examinations can be large. As the locations are specified by a 'deterministic code' they cannot be varied.

In contrast RI-ISI methodologies offer the opportunity to vary the selection of inspection sites provided the level of risk reduction is maintained. Inspection sites are typically divided into two categories:

- Inspections for Cause – sites that are identified as being potentially susceptible to a degradation mechanism based on screening criteria developed from service experience and understanding of the degradation mechanism.
- Inspections for DiD – inspection sites where a degradation mechanism has not been identified as operative, but the consequence of failure is high.

Consider the illustrative risk matrix in Table 1. The locations that have been identified as susceptible to a particular type of degradation are included as part of the RI-ISI programme due to their high-risk characteristic ('red boxes'). The locations in the 'green boxes' are not considered as candidates for ISI based on their relative risk ranking. The 'yellow boxes' are provided to address risk outliers, DiD and uncertainty. For example, there are several sites which have a low failure potential but have a high consequence of failure and could have an important impact on the plant if they fail ('DiD box'). Thus, in a RI approach to ISI, even though these locations are quantitatively low risk, from a DiD perspective some amount of inspection is warranted. However, for these DiD locations because there is no degradation mechanism of interest, examinations in lower dose areas can typically be selected.

Table 1. Illustrative Risk Matrix and Defence-in-Depth.

		Conditional Consequences		
		Low	*Medium*	*High*
Failure Potential	*High*			
	Medium			
	Low			*DiD*

Figure 4 illustrates the achieved dose reductions for one large PWR plant in the U.S. that implemented RI-ISI on Class 1 and Class 2 piping. Many other plants (BWRs and PWRs) have reported similar dose savings [12].

Finally, when implementing a RI-ISI programme there are also comparable reductions in the radioactive waste associated with conducting NDE as compared to deterministic ISI programmes, which are more difficult to quantify as many of the disposable items (such as gloves, booties, overalls) are purchased in bulk quantities. In addition to worker clothing there are other consumables used during the performance of the ISI/NDE task, such as paper, plastic bags/covers and other material used to clean up the surface after a liquid penetrant or magnetic particle examination as well as the couplant used during an ultrasonic examination.

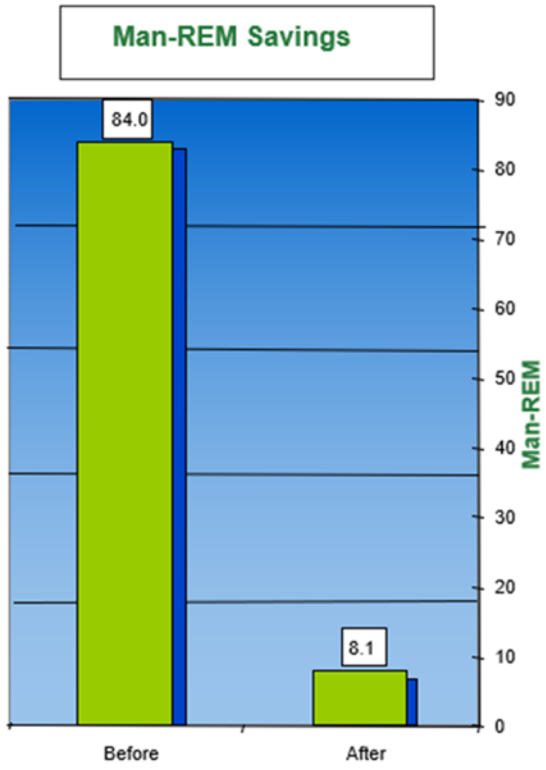

Figure 4. Example of dose reduction due to RI-ISI application. (© EPRI)

4.5. Personnel Safety

As most operating NPPs were not designed for ISI, locations selected for inspection by deterministic codes and standards often result in challenges to personnel safety beyond high dose and temperature environments. The locations selected for inspection are often difficult to access, in areas that limit physical movement and are located where automated equipment and remote tooling is difficult to use. Using similar considerations to those described in Section 4.4, personnel safety and access can be considered in ISI site selection.

4.6. Outage Management

As discussed in the previous sections, deterministic ISI requirements are primarily focused on systems classified as safety related Class 1 or Class 2. Consequently, the inspections required by deterministic ISI codes and standards can only be implemented during plant shutdown.

As noted previously, many of these locations were not designed for straightforward access to perform ISI and often require that scaffolding be installed, and insulation removed prior to conducting the inspection. Additionally, some deterministic ISI codes and standards require that radiographic techniques be used which requires that entire plant areas be cordoned off and that all other work be stopped in that area until the examination has been completed.

Utilizing RI-ISI to reduce the number of inspections that provide minimal safety benefit and better focusing resources on the most important locations naturally leads to a positive impact on outage planning, scheduling, and cost. RI-ISI also simplifies outage implementation as for those locations that require inspection by the RI-ISI methodology, there is more flexibility to minimize scaffolding, insulation removal, and choosing low dose areas while also gaining better examination coverage.

5. European Experience of Safety Benefits Using RI-ISI

The examples of the benefits of adopting a RI-ISI approach are based largely upon the wide experience of U.S. applications. Within Europe the application of RI-ISI has been more limited, but nevertheless a number of examples exist and are summarised below by country. Among the European countries operating NPPs, the regulatory bodies of Sweden and Finland require the use of a RI approach to ISI. In Spain and Slovenia, the regulatory bodies have also approved the use of RI-ISI and pilot applications have been performed in several other countries. A comprehensive summary of RI-ISI experience in Europe was published by ENIQ in 2017 [13].

5.1. Sweden

The Swedish regulatory body introduced a qualitative RI ISI requirement in its regulation SKIFS 1994:1, which has later been transferred to regulatory guide SSMFS 2008:13 [14]. Since regulation SKIFS 2000:2 was introduced, the methodology used to develop the ISI programme must be submitted and approved by the regulatory authority.

The methodology is a deterministic risk driven approach that uses a damage and consequence index to rank the different systems. The piping segments are divided into three control groups considering the relative risks for nuclear fuel damage, release of radioactive substances, accidental chain-reaction, and deficiencies in the safety level. In general, each risk is considered to arise as a result of damage occurring to a mechanical component or system. This has been applied at all Swedish NPPs.

At Ringhals NPP (a Westinghouse design), in addition to the SKIFS 1994:1, two other quantitative RI-ISI methodologies have been applied: a relative and an absolute risk ranking. The RI-ISI programme, and locations and systems included within it, have therefore varied over time.

Application of SKIFS 1994 resulted in an ISI programme with locations that tended to be concentrated in the vicinity of the RPV. A full scope RI-ISI evaluation was applied and a more significant change to the ISI programme was evident. Use of a RI-ISI methodology based on relative risk ranking led to a shift of inspection sites to lower safety class systems, typically outside of the scope of deterministic codes. For example, several Balance-Of-Plant (BOP) systems were included (Condensate, Component Cooling, Fire Water and Bleed Steam system).

After the last transition to the methodology with absolute risk ranking a movement of inspection areas toward higher safety class systems was recognized, but still included a BOP system.

There have been two clear benefits from moving to a RI-ISI programme in terms of NPP safety and dose reduction for workers. There has been a factor of two reduction in Core Damage Frequency and a reduction in dose uptake of 58 % over a ten-year period for workers at Ringhals NPP.

5.2. Finland

In Finland, the use of a RI methodology to establish the ISI programme has been a regulatory requirement since 2004, and is included in the current YVL guide by regulator STUK [8]:

"The piping in-service inspection programme shall be prepared in a risk-informed manner, analysing all of the nuclear facility's systems in safety classes 1, 2, 3, and EYT (non-nuclear) as a single complex independently of the safety classifications and nominal dimensions of the piping."

Loviisa NPP (a VVER design) has a RI-ISI programme for piping systems based on a PSA. Each piping system is divided into segments for degradation classification, if the Conditional Core Damage Probability (CCDP) is greater than 10^{-6}. Based on the RI-ISI analysis, many segments other than nuclear safety Class 1 or 2 systems are now included within the ISI programme. The RI-ISI analysis has led to the selection of approximately 900 ISI locations in 31 systems. However, most of these locations are still within safety classified systems on the primary circuit. It should be noted that several segments within non-safety classified systems (such as the Feed Water System and Steam System) were assigned the highest failure consequence class, whereas safety classified systems on the primary side contained segments with CCDP values a decade smaller.

In the analysis of fire protection piping system, increased nuclear safety risk (CCDP > 10^{-4}) was identified in some segments within the Steam Generator room area. One of the recognised scenarios was flooding leading to the potential for significant damage to (some) components in that area. Consequently, both an inspection programme was invoked and consideration of plant redesign to reduce the risk.

The RI-ISI approach at Olkiluoto 1 and 2 Boiling Water Reactor (BWR) units follows largely the same principles as that at Loviisa NPP: a full scope RI-ISI programme with extensive use of the plant PSA model, qualitative analysis of failure potential, and the use of an independent expert panel to review the risk ranking [15][16]. The classification of degradation potential is different from both Loviisa NPP and EPRI approaches since Intergranular Stress Corrosion Cracking (IGSCC) is one of the main expected degradation mechanisms in a BWR.

At Olkiluoto, the change from the deterministic ISI programme to RI-ISI has not had a significant impact on the total number of inspections, but there were significant changes in the selection of ISI locations. More inspections were focused on piping segments that may have a low potential for IGSCC, but are identified by PSA as having relatively high consequences. Inspections were increased in the Feedwater System and in the Relief System. The Recirculation System and Boron System were added as new systems to the ISI programme following the identification of high consequences of pipe breaks in some segments.

When determining new inspection sites, one criterion has been the minimisation of doses to the inspection personnel. Overall, inspections were reduced in areas of high dose.

5.3. Spain

Spanish regulation requires that NPPs meet 10 CFR50.55a and therefore the requirements of ASME Section XI Division 1 [5]. The Spanish regulatory body – the Nuclear Safety Council (Consejo de Seguridad Nuclear; CSN) – considers RI-ISI an acceptable approach in lieu of the ISI requirements of ASME Section XI [5]. Both CSN and the Spanish nuclear industry consider that the implementation of a RI-ISI programme makes pipe inspections more efficient, guaranteeing or even increasing the safety and availability of the plants whilst optimising the operating and maintenance costs, and reducing the dose uptake by personnel. This is included in the CSN Safety Guide 1.17 [17] and the CSN-Unesa RI-ISI-02 Guide [18], both of which describe the methodology for developing a RI-ISI programme based on the quantitative methodology developed by Westinghouse.

The scope of the RI-ISI programmes in Spain focuses on pipes, with differences between NPPs in terms of the class of pipes considered. In general, Spanish NNPs that have chosen to establish an RI-ISI programme have done so for Class 1 piping, except Cofrentes NPP, which has even extended the analysis to Class 2 piping.

After the implementation of a RI-ISI programme, the number of sites to be inspected has been considerably reduced, even though the number of welds in the scope of the programme has increased significantly. This guarantees that all those important for safety are inspected and that, in turn, the risk in terms of Core Damage Frequency of Large Early Release Frequency, has been reduced or maintained.

Additionally, it has been possible to obtain a series of benefits that have resulted in improvements to the safety of the installation. With a better knowledge of the importance of the different degradation mechanisms that affect the piping, including some not considered initially, it has been possible to focus resources on those that have a greater contribution to the risk. The reduction in the number of inspections to be carried out has also meant a reduction in the dose received by the inspection personnel.

5.4. Slovenia

Krško NPP is a Westinghouse designed two loop PWR that follows U.S. NRC regulatory requirements. Krško NPP has developed RI-ISI programme for Class 1 and 2 piping according to ASME Section XI, Non-mandatory Appendix R, Risk-Informed Inspection Requirements for Piping, Method B.

The RI-ISI programme added several risk-significant welds to the existing ISI programme, which has resulted in a significant improvement to plant safety. Furthermore, the worker dose uptake has been reduced by approximately 30% (based upon experience from two first outages with RI-ISI). The dose reduction was primarily due to the reduction of scaffolding, insulation dismantling and surface examinations.

6. Conclusions

RI-ISI provides rational plant safety management informed by the results of plant-specific risk analyses. The fundamental principle is to identify safety significant locations where the inspection efforts should be concentrated and to provide an on-going improvement in the overall plant and personnel safety together with reduced radiation doses for the inspection personnel.

RI-ISI offers significant benefits over conventional deterministic programmes in terms of:

- Maintaining or reducing plant risk relative to the value associated with ISI sites selected via deterministic codes;
- Providing a detailed understanding of piping system failure modes including both direct and secondary consequences of failure;
- Improved flexibility in selection of ISI locations;
- Providing a more accurate estimate of the operating NPP risk profile;
- More effective inspection for degradation mechanisms of concern;
- Reducing radiation dose uptake by workers;
- Increasing personnel safety;
- Improved outage management.

Worldwide experience with the use of RI-ISI provides a foundation for understanding the safety benefits of RI-ISI. This experience illustrates many common themes from the application of RI methods including better inspection locations, better inspections, safety improvements beyond NDE as well as extension of the scope of ISI sites to safety related and non-safety related pipework systems outside of the scope of deterministic codes. Additional pipework systems are generally included within the scope as a result of the secondary effects following postulated failure (for instance, flooding or jet impingement).

References

[1] Evaluation of the PISC II trials results. PISCII Report No. 5. OECD – Nuclear Energy Agency, September 1986.

[2] Report from the Plate Inspection Steering Committee on the ultrasonic examination of three test plates using the PISC procedure based upon the ASME XI Code. OECD – Nuclear Energy Agency, November. 1979.

[3] Symposium on 'The UKAEA Defect Detection Trials', UKAEA, Risley, Warrington 7th-8th Oct. 1982. Published in British Journal of Non-Destructive Testing, vol 25, November 1983.

[4] European Methodology for Qualification of Non-Destructive Testing. ENIQ Report No. 61, Issue 4.

[5] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code Section XI Rules for Inservice Inspection of Nuclear Power Plant Components, Division I.

[6] ENIQ Framework Document for Risk-Informed In-Service Inspection. ENIQ Report No. 51, Issue 2.

[7] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code Section III Rules for Construction of Nuclear Facility Components, Division I.

[8] STUK Guide YVL E.5. In-Service Inspection of Nuclear Facility Pressure Equipment with Non-Destructive Testing Methods.

[9] Report on the Regulatory Experience of Risk-Informed Inservice Inspection of Nuclear Power Plant Components and Common Views. Prepared by the Nuclear Regulators' Working Group Task Force on Risk-Informed Inservice Inspection. Final Report – August 2004.

[10] American Nuclear Society Standards Committee Working Group ANS-51.1, Nuclear Safety Criteria for the Design of Stationary Pressurized Water Reactor Plants. ANSI/ANS-51.1–1983.

[11] American Nuclear Society Standards Committee Working Group ANS-52.1, Nuclear Safety Criteria for the Design of Stationary Boiling Water Reactor Plants. ANSI/ANS-52.1-1983.

[12] Technical Brief #3002020582, Use of a Risk-Informed Inspection Process to Reduce Labor and Contract Costs, EPRI 2021.

[13] ENIQ Technical Report. Lessons Learned from the Application of Risk-Informed In-Service Inspection to European Nuclear Power Plants. ENIQ Report No. 48.

[14] Swedish Radiation Authority Code of Statutes. SSMFS 2008:13 The Swedish Radiation Safety Authority's Regulations and General Advice on Mechanical Components in Nuclear Power Plants.

[15] Current Status and Experience of Application of RI-ISI in Finland, Risk Informed Piping Integrity Management Workshop 2008, Madrid, NEA/SEN/SIN/IAGE (2008).

[16] Applications of the TVO Piping and Component Analysis and Monitoring System (PAMS). Transactions, SMiRT-22, San Francisco, California, USA - August 18-23, 2013, Division III.

[17] CSN Safety Guide 1.17: Application of Risk-Informed Techniques to In-Service Inspection (ISI) of Pipelines. July 2007.

[18] CSN-Unesa Guide RI-ISI-02. Guide for the Conduct and Evaluation of Risk-Informed In-Service Inspection Programs of Pipelines. May 2000.

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ENIQ

European Network for Inspection & Qualification

NUGENIA Technical Area 8

ABOUT ENIQ AND NUGENIA

The **European Network for Inspection and Qualification (ENIQ)** is a utility driven network working mainly in the areas of qualification of non-destructive testing (NDT) systems and risk-informed in-service inspection (RI-ISI) for nuclear power plants (NPPs). Since its establishment in 1992 ENIQ has issued over 60 documents. Among them are the “European Methodology for the Qualification of Non-Destructive Testing” and the “European Framework Document for Risk-Informed In-Service Inspection”. ENIQ is recognised as one of the main contributors to today’s global qualification guidelines for in-service inspection.

ENIQ is the technical area 8 of NUGENIA, one of the three pillars of the Sustainable Nuclear Energy Technology Platform (SNETP) that was established in September 2007 as a R&D&I platform **to support technological development for enhancing safe and competitive nuclear fission in a climate-neutral and sustainable energy mix.** Since May 2019, SNETP has been operating as an international non-profit association (INPA) under the Belgian law pursuing a networking and scientific goals. It is recognised as a European Technology and Innovation Platform (ETIP) by the European Commission.

The international membership base of the platform includes industrial actors, research and development organisations, academia, technical and safety organisations, SMEs as well as non-governmental bodies.

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