For Official Use **NEA/CSNI/R(2005)9**

Organisation de Coopération et de Développement Economiques
Organisation for Economic Co-operation and Development

28-Jul-2005

English text only

NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

NEA/CSNI/R(2005)9
For Official Use

CSNI INTEGRITY AND AGEING WORKING GROUP

STATUS REPORT ON DEVELOPMENTS AND COOPERATION ON RISK-INFORMED IN-SERVICE-INSPECTION AND NON-DESTRUCTIVE TESTING (NDT) QUALIFICATION IN OECD-NEA MEMBER COUNTRIES

JT00187983

English text only

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Pursuant to Article 1 of the Convention signed in Paris on 14th December 1960, and which came into force on 30th September 1961, the Organisation for Economic Co-operation and Development (OECD) shall promote policies designed:

- to achieve the highest sustainable economic growth and employment and a rising standard of living in member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;
- to contribute to sound economic expansion in member as well as non-member countries in the process of economic development; and
- to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.

The original member countries of the OECD are Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The following countries became members subsequently through accession at the dates indicated hereafter: Japan (28th April 1964), Finland (28th January 1969), Australia (7th June 1971), New Zealand (29th May 1973), Mexico (18th May 1994), the Czech Republic (21st December 1995), Hungary (7th May 1996), Poland (22nd November 1996), Korea (12th December 1996) and the Slovak Republic (14 December 2000). The Commission of the European Communities takes part in the work of the OECD (Article 13 of the OECD Convention).

NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1st February 1958 under the name of the OEEC European Nuclear Energy Agency. It received its present designation on 20th April 1972, when Japan became its first non-European full member. NEA membership today consists of 28 OECD member countries: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, Norway, Portugal, Republic of Korea, the Slovak Republic, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The Commission of the European Communities also takes part in the work of the Agency.

The mission of the NEA is:

- to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes, as well as
- to provide authoritative assessments and to forge common understandings on key issues, as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.

Specific areas of competence of the NEA include safety and regulation of nuclear activities, radioactive waste management, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has a Co-operation Agreement, as well as with other international organisations in the nuclear field.

COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

The NEA Committee on the Safety of Nuclear Installations (CSNI) is an international committee made up of senior scientists and engineers, with broad responsibilities for safety technology and research programmes, and representatives from regulatory authorities. It was set up in 1973 to develop and co-ordinate the activities of the NEA concerning the technical aspects of the design, construction and operation of nuclear installations insofar as they affect the safety of such installations.

The committee's purpose is to foster international co-operation in nuclear safety amongst the OECD member countries. The CSNI's main tasks are to exchange technical information and to promote collaboration between research, development, engineering and regulatory organisations; to review operating experience and the state of knowledge on selected topics of nuclear safety technology and safety assessment; to initiate and conduct programmes to overcome discrepancies, develop improvements and research consensus on technical issues; to promote the coordination of work that serve maintaining competence in the nuclear safety matters, including the establishment of joint undertakings.

The committee shall focus primarily on existing power reactors and other nuclear installations; it shall also consider the safety implications of scientific and technical developments of new reactor designs.

In implementing its programme, the CSNI establishes co-operative mechanisms with NEA's Committee on Nuclear Regulatory Activities (CNRA) responsible for the program of the Agency concerning the regulation, licensing and inspection of nuclear installations with regard to safety. It also co-operates with NEA's Committee on Radiation Protection and Public Health (CRPPH), NEA's Radioactive Waste Management Committee (RWMC) and NEA's Nuclear Science Committee (NSC) on matters of common interest.

FOREWORD

Nuclear power production in many countries relies on a population of ageing plants. Their safe and reliable performance is of utmost importance, both for the owners and for the countries, which to a larger or lesser degree depend on nuclear power for their electricity supply. At the same time, nuclear power plants face increasing economic pressures in many countries due to fierce competition in deregulated electricity markets. This leads to a pressure to cut operation and maintenance costs and at the same time to improve plant availability and reliability. There are also trends towards extending operational life beyond the original design lifetime both to make best use of investments made and in view of the political difficulties encountered in many countries with respect to siting and licensing new reactors or various other types of electricity production capacity.

During the last decades the nuclear industry has experienced service degradation of many components, both in primary systems and in secondary systems. Several inspection failures have also occurred over the years.

This degradation and inspection history as well as the economical and political factors have consequently set up a pressure for more efficient and cost-effective in-service inspection programmes to ensure that there are adequate safety margins so that anticipated degradations of components do not lead to failures that cause accidents or even unplanned shutdowns with adverse effects on power production reliability. In this situation, nuclear regulators as well as nuclear utilities in many countries have developed and implement risk-informed inspection approaches together with more stringent requirements of demonstrating the performance of the NDT systems that are to be used for inspection of safety related components which are susceptible to different kind of degradation mechanisms.

In December 2000, the Committee on Nuclear Regulatory Activities (CNRA) and the Committee on the Safety of Nuclear Installations (CSNI) agreed to prepare a state-of-the art report addressing the present situation and regulatory aspects in NEA member countries on:

- Risk based/risk informed in-service inspections developments,
- Qualification of NDT system to be used for the inspections.

The CSNI gave mandate to the CSNI working group on the Integrity of Components and Structures (IAGE) to prepare the report.

Practices and status in NEA member countries were collected in 2003 through a questionnaire. Results have been compiled in the report NEA/CSNI/R(2005)3 [1]. To complete the technical information, a CSNI Workshop was held from 13 to 14 April 2004 in Stockholm, Sweden hosted by the Swedish Nuclear Power Inspectorate. The Workshop gathered 54 participants from 17 countries including the EC, the IAEA and the main organisations worldwide developing RI-ISI methodologies. Papers presented at the Workshop have been published in the proceedings referenced NEA/CSNI/R(2004)9 [2].

The reports [1] and [2] along with the NRWG-report EUR 21320 [3] are the main source of information for this Status Report on Developments and Cooperation on Risk-Informed In-Service-Inspection and Non-Destructive Testing (NDT) Qualification in OECD-NEA member countries.

ACKNOWLEDGEMENT

Gratitude is expressed to Mr Lars Skanberg, Director of the Department of Reactor Technology and Structural Integrity at the Swedish Nuclear Power Inspectorate for compiling this report.

EXECUTIVE SUMMARY

During the nineties it became clear that the methods of probabilistic risk or safety assessments (PSAs) provided an enhanced understanding of the consequences of component failures. Furthermore, the accumulation of plant operating experience along with the development of probabilistic structural mechanics methods gave better insights for identifying structural locations that were most likely to fail. In the mid nineties, the regulatory risk-informed approach was developed in the USA, and began to emerge in many other countries. The term “risk-informed” was introduced. It characterises an approach, where insights from risk assessment are considered together with other factors to make integrated decisions.

The basic idea of risk informed in-service inspection, RI-ISI, is to integrate service experience, plant and operating conditions, additional deterministic information, and risk insights. This means that RI-ISI is plant-specific. The main role of risk in the process is to guide the ranking of segments or locations and thereby support decisions on locations to be inspected. Evaluation of the risk requires identification of anticipated degradation mechanisms and how likely these are to lead to various failure modes. The anticipated degradation mechanisms may be used to guide inspection methods whilst the kinetics of the anticipated degradation mechanisms may be used to guide the frequency of inspections.

The basic objective of RI-ISI is to make ISI programs more effective and efficient from a safety and economic point of view. Worker radiation exposure should also be reduced.

Requirements and regulatory guidance for introduction of RI-ISI have been established in several countries as well as important aspects to be considered. Examples of such important aspects are:

- methods and procedures used must be repeatable, adequately justified, and traceable;
- all input data to the process must be justified and subject to quality assurance;
- components‘ susceptibility to different kinds of degradation mechanisms must be determined thoroughly;
- structural reliability models (SRMs) / probabilistic structural mechanics models and associated software, which are used to estimate failure probabilities, should be verified and validated;
- direct and indirect effects of all component failure modes (e.g., small leak, large leak, break) have to be considered;
- the PSA should reflect the actual status and operational practices of the plant. It should use best estimate models and data, as opposed to conservative assumptions. Living Level 1 PSA is a prerequisite.

It is also important that RI-ISI programmes are living programmes. Performance measurement strategies should be used to account for uncertainties in the analyses, to provide feedback and updating in due time, and to confirm the approach. RI-ISI, as well as other ISI programmes, must be regularly updated to take the new information into account that could have an impact on the programme. The information from detected degradations, component failures, and damage analyses as well as enhanced knowledge on degradation mechanisms and influential factors should be incorporated into RI-ISI programmes continuously. Other changes such as PSA updates and plant design and operating changes should be considered periodically.

Several RI-ISI approaches have been developed based on quantitative, semi-quantitative or qualitative methodologies. Some of these methods are used in practical applications, others have been evaluated in pilot studies.

The existing qualitative methods are transparent and relatively easy to understand. They emphasise the most important features, i.e., susceptibility to or relevance of degradation mechanisms and severity of consequences. Assigning the items of the scope to broad range regions of risk and incorporating allowances for uncertainties, they conservatively discriminate “low” risk from “high” risk. The qualitative methods tend to be robust provided they include suited decision criteria and are properly prescribed.

The existing quantitative methods using structural reliability models provide better discernment and resolution than qualitative methods. In addition, they offer capabilities to tailor and optimise inspection strategies. The results, however, can only be correct, if the models, computing codes, and input data reflect the actual plant conditions. Some of methods make only limited use of these possibilities. Other methods aim at fully exploiting the possibilities offered by the quantitative methodology.

RI-ISI is presently used in three countries, Spain, Sweden and United States and is considered in several countries to various extents.

In United States RI-ISI is non mandatory and can be used as an alternative to ISI programmes for piping systems based on the requirements in ASME Section XI. So far RI-ISI programmes have been approved for 52 plants and 17 are currently under review. It is expected that also the remaining plants will apply RI-ISI. Both quantitative and semi-quantitative methods are used. The augmented ISI programs have remained unchanged.

In Spain several applications for RI-ISI programmes have been approved for piping systems. These are based on a quantitative method. The approved RI-ISI programmes are restricted to class 1 piping, but recommendation for extending the RI-ISI programme to a full scope application exist. RI-ISI is non mandatory and can be used to as an alternative to present ISI programmes.

In Sweden RI-ISI is mandatory since 1992 for ISI of piping systems and other components except reactor pressure vessels, steam generators and containment. A qualitative RI-ISI approach has been in place since 1988. It includes all known degradation mechanisms. No additional augmented ISI programs are therefore required. The first RI-ISI programme based on a quantitative method has recently been approved. It is expected that at least two other plants will apply for RI-ISI based on this quantitative method.

Also in Finland RI-ISI is mandatory, but only for new reactors. Existing plants may decide to continue with the present ISI programmes.

Pilot studies of different RI-ISI approaches for piping systems have been performed in Germany, Finland, France, Japan, Korea, Sweden, Switzerland and United States to test the methods and to gain experience.

Development of RI-ISI approaches for other components such as reactor pressure vessels and reactor containment have been initiated in some countries.

NDT qualification requirements have been introduced or are on the way of being introduced in most countries engaged in nuclear power generation to secure reliable inspections of identified ISI items. The requirements are based on the recognition that all part of an NDT system affects its performance. Equipment, techniques, procedures as well as NDT operator should therefore be included in the assessment of the NDT effectiveness. The introduced NDT qualification requirements are either in the form of regulations or regulatory guides or in the form of individual plant licence conditions. Transition periods still apply in some countries, but the requirements will become fully effective in the near future. Where formal requirements are not regulatory practice, there are clearly expressed regulatory expectations for NDT qualifications.

In addition to mandatory qualifications, non-mandatory qualifications are performed in many countries.

Conclusions

Major changes of ISI approaches have been introduced during the last decade. The evolution of PSA methodology has provided an enhanced understanding of the consequences of component failures. This progress together with the accumulation of plant operating experience and the development of probabilistic structural mechanics methods have found basis for RI-ISI.

The concepts of RI-ISI have successfully been implemented in several countries and are now along with NDT qualification providing improved ISI that both reduce plant risks and radiation exposure to inspection personnel. These benefits have been achieved at the end of a long period of development and implementation.

The concept of NDT qualification has been implemented in most countries. Implementation experience to date indicates that NDT qualifications have contributed to more reliable NDT systems for ISI. Qualified NDT-systems, in general, performs well. There is confidence in their capability and reliability. Decision making during the NDT process have become more transparent and convincing.

Implementation experience to date and results of pilot studies show however that further evaluations and developments of RI-ISI and NDT qualification approaches are needed.

Recommendations

Based on the questionnaire [1] and discussions at the OECD Workshop on RI-ISI and NDT qualification [2] the following recommendations are made:

Further evaluations

- Comparative RI-ISI method performance study by applying several of the existing qualitative and quantitative methods to the same specific scope of piping in one or two plants, and comparing the results in terms of the extent, the number and the locations of inspection sites;
- Evaluation of differences in ISI selection when applying a quantitative method to a specific scope of piping in a plant with and without leak detection, and comparing the results in terms of the extent, the number and the locations of inspection sites as well as resulting requirement on the leak detection system capabilities and demands on operator actions;
- Further benchmarking and validation of existing structural reliability models (SRMs) / probabilistic structural mechanics models and associated software;
- Evaluation of the influence of different assumptions about probability-of-detection (POD) curves and independent versus dependent inspections on calculated failure rates.

Further developments and co-operation

- Continued support to the international degradation and damage data base OECD Piping Failure Data Exchange (OPDE);
- Cooperative actions to establish consensus criteria for component susceptibility to different kind of degradation mechanisms;
- Continued exchange of experience from RI-ISI applications and pilot studies;
- Cooperative actions to develop and extending RI-ISI methodologies to other components and safety related structures;
- Continued exchange of experience from NDT qualifications including developments of techniques for production of test blocks with realistic defect simulations.

TABLE OF CONTENTS

I INTRODUCTION

In-service inspection (ISI) is an important measure in the defence-in-depth strategy[1]for the assurance of physical barrier integrity and the avoidance of failure, placing special attention on the in-service inspection of the primary coolant system boundary. Thus, the objectives are twofold:

- ISI is intended to reveal any flawed conditions of pressure boundary components and their supports that might lead to failures and thereby affect the safety of the plant. In particular, service-induced degradation of the pressure boundary should be detected at an early stage in order to prevent leakage or rupture.
- ISI is relied upon to verify that design assumptions are maintained and to demonstrate the components' continued acceptability for service with an adequate safety margin against failure. This is to provide information about the components' current condition and to provide assurance in their future structural integrity.

Regarding the objectives, it is necessary that ISI addresses both foreseen and unforeseen or unexpected degradations. Operating experience shows that most problems have been caused by damage mechanisms which were not foreseen.

The efficiency of applied ISI programmes, and thereby how well they can fulfil their role, depends on many factors such as strategies and procedures to

- identify and rank reactor system parts and components in which failure can have an impact on the safety level,
- identify components which can be degraded by different kinds of operating conditions,
- determine ISI intervals and the extent frequency of inspections,
- demonstrate that the performance of non-destructive testing (NDT) systems to be used during ISI are able to meet its goals.

I.1 Early ISI strategies

The design arrangements of components in fossil-fuelled power plants has always taken into account the need for ready access to all components to facilitate inspection, maintenance, repairs, and replacement of components as required. With the development of nuclear power plants in the early 1960s, system designers initially believed that periodic in-service inspection of passive components in the reactor coolant pressure boundary would be impractical due to the radioactivity of the systems. The system designers also assumed that ISI would be unnecessary provided the components were designed, constructed and manufactured to higher quality standards than those applied to fossil-fuelled power plants. Consequently, very limited attention was given to the need for ISI in the early nuclear power plants and the systems were not provided with adequate access for the inspection of many important components. As the number of nuclear power plants in service increased concerns about the possibility of service induced defects were however raised. Therefore, the nuclear industry and the regulatory bodies began to develop criteria for ISI.

[1] Defence In Depth in Nuclear Safety, INSAG 10. A report by the International Nuclear Safety Advisory Group. International Atomic Energy Agency, 1996.

Many of the early codes used safety classification for identification of those components whose malfunction or structural failure could potentially impair the safe continued operation and thereby would be merited for surveillance measures throughout the service lifetime of the plant. The selection of specific areas to be inspected in each component category was to be based on factors such as:

- environmental condition, such as irradiation that could cause embrittlement of the reactor vessel belt-line,
- operational transients, such as system start-ups and shutdowns, which could induce fatigue as a result of cyclic strains,
- component design configurations identified with higher stress field, such as vessel nozzles, weld joints, and structural discontinuities between piping, pumps and valves,
- material properties of dissimilar metal joints, such as weld joints between austenitic stainless steel and ferritic steels that may be subject to additional thermal strains in service.

I.2 Augmented ISI and NDT Qualification

During the late 1970s and early 1980s component failures due to different types of cracking and other types of degradation were observed in several nuclear power plants in many countries. The cracking and degradation problems were in many cases discovered by leakage, and not by ISI. These observations led to concerns about the efficiency of the inspection programmes that followed ASME Section XI[2]and similar codes which prescribed the selection of specific areas to be inspected, more or less on the basis of design stresses. Regulatory bodies therefore began to require additional inspections that were more focused on different types of degradation mechanisms. Augmented inspection programmes were consequently developed for specific mechanisms such as intergranular stress corrosion cracking (IGSCC) in piping, high-cycle thermal fatigue in piping and nozzles, erosion-corrosion in piping, etc.

Several inspection failures have also occurred over the years, and international round-robin studies, such as PISC programme[3], and similar national exercises have been performed to measure or estimate NDT performance. Many of these exercises have shown discouraging defect detection and defect sizing performance plus a large variability between participating inspection teams, even between teams using similar inspection procedures.

This inspection failure history lead to the development and implementation performances based qualification methodologies for assessment of the effectiveness of NDT systems to be used in some augmented inspection programmes.

---

[2] ASME Boiler and pressure vessel code, Section XI, Rules for in-service inspection of nuclear power plant components. The American Society of Mechanical Engineers.

[3] Programme for Inspection of Steel Components. Joint OECD and EU research programme.

II RISK-INFORMED IN-SERVICE INSPECTION (RI-ISI)

II.1 Development of RI-ISI strategies

During the 1990s it became clear that the methods of probabilistic risk or safety assessments (PSAs) provided an enhanced understanding of the consequences of component failures. Furthermore, the accumulation of plant operating experience along with the development of probabilistic structural mechanics methods gave better conditions for identifying those structural locations that are most likely to fail. In the mid nineties, the regulatory risk-informed approach was developed in the USA, and began to emerge in several European countries. The term "risk-informed" was introduced by the U.S. Nuclear Regulatory Commission, NRC. It characterises an approach, where insights from risk assessment are considered together with other factors to make integrated decisions.

The basic idea of risk informed in-service inspection, RI-ISI, is to integrate service experience, plant and operating conditions, other deterministic information, and risk insights. This means that RI-ISI will be plant-specific. The main role of risk in the process is to guide the ranking of segments or locations and thereby support decisions on locations to be inspected. Evaluation of the risk requires identification of anticipated degradation mechanisms and how likely these are to lead to various failure modes. The anticipated degradation mechanisms may be used to guide inspection methods whilst the kinetics of the anticipated degradation mechanisms may be used to guide the frequency of inspections.

The basic objective of RI-ISI is to make ISI programs more effective and efficient from a safety and economic point of view. Worker radiation exposure should also be reduced.

II.2 RI-ISI Regulatory guidance

During the late 1990's, significant advancements were made in the U.S. development of RI-ISI methods, industry consensus standards, and regulatory guidance. Two primary RI-ISI methods were developed and which describe how RI- ISI programs can be elaborated and implemented for selected piping in operating nuclear power plants. One methodology was developed by the Electric Power Research Institute (EPRI). The other methodology was developed by the Westinghouse Owners Group (WOG). These methods along with the results of several pilot plant applications were submitted to the NRC for review and approval.

In 1998, the NRC published a trial use version of Regulatory Guide 1.178[4]. As stated therein, this regulatory guide issued for trial use did not establish any final staff positions. This regulatory guide and its companion Standard Review Plan, Section 3.9.8 of NUREG 0800 were used to support the review and approval of both industry-developed methodologies. Consistent with Regulatory Guide 1.174[5], this regulatory guide focuses on the use of PRA in support of a RI-ISI program. The guide provides guidance on acceptable risk informed approaches that are consistent with the basic elements identified in Regulatory Guide 1.174 for meeting the existing Section XI requirements for the scope and frequency of inspection of ISI programs and provide an acceptable level of quality and safety.

---

[4] U.S.NRC, "An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis", Regulatory Guide 1.174

[5] U.S.NRC, "An Approach for Plant-Specific Risk-Informed Decision making, In-service Inspection of Piping", Regulatory Guide 1.178

In September 2003, based on the experience during the review and approval of the industry methodologies and the review and approval of numerous plant specific relief requests for in-service inspection programs, the NRC staff issued an updated version of Regulatory Guide 1.178. This updated regulatory guide and corresponding standard review plan is no longer for trial use.

The five key safety principles of RG 1.174 are:

1. The proposed change meets the current regulation.
2. Defence-in-depth is maintained.
3. Sufficient safety margins are maintained.
4. An increase in risk should be small and consistent with the Commission's safety goals.
5. The impact of the proposed change is monitored by using performance measurement strategies.

In Europe the Nuclear Regulators' Working Group (NRWG) decided in November 1996 to set up a task force (TF) to agree on the philosophy and principles governing RI-ISI of mechanical components of Nuclear Power Plants in order to maintain sufficient margins against leakages and failures, considering dose exposures to the public. The TF performed a review and inventory of the existing approaches to RI-ISI, and completed its work in 1999 with a Current Practices Document, titled "Report on risk-informed in-service inspection and in-service testing" (EUR 19153 EN). As a follow-up in May 2002, the TF was reconvened and produced in 2004 a "Report on the regulatory experience of risk-informed in-service inspection of nuclear power plant components and common view" (EUR 21320 EN). The common views, as stated in this document, are agreed in general by all the participating regulatory bodies of the European Union[6], or their representatives. They express what should be considered by the regulatory body when establishing guidelines on RI-ISI and assessing licensees' RI-ISI applications. They are not to be understood as a regulatory commitment to the introduction of RI-ISI programmes. Whether RI-ISI programmes are introduced is and will be decided at the national level.

Key Principles have been established in the report with reference to the NRC Regulatory Guide RG 1.174 and taking into account INSAG 10 and 12, but are somewhat more specific to ISI and are adapted to European needs. In the common view on important aspects, the Key Principles are developed into more detail, and further basic safety principles as well as methodological aspects of regulatory concern are addressed.

The common view on key principles is:

1. The introduction of risk-informed in-service inspection must be in accordance with the legal and regulatory framework of the European countries
2. An ISI programme must be in place that is consistent with the defence-in-depth philosophy
3. Risk-informed changes to ISI programmes must maintain safety margins against leakage and failure
4. Risk should be reduced to a level derived from national legal requirements, regulations and regulatory guidance. When changing to a risk-informed ISI programme, risk reduction or neutrality should be achieved
5. RI-ISI programmes should be monitored using performance-measurement strategies

[6] and Switzerland.

II.3 Important aspects of RI-ISI

In addition to key and safety principles there are some important aspect of RI-ISI that must be taken into account when developing new ISI programmes. These important aspects relates to methods, procedures, scope of RI-ISI applications, quality of input data, failure and consequence analysis and risk assessments.

Such important aspects were addressed in the IAGE-questionnaire and are also elaborated in the NRWG-report [3]. There is a common view that for example

- methods and procedures used must be repeatable, adequately justified, and traceable. New methods and new or extended applications with existing methods should be evaluated through pilot studies. The procedures should be robust and stable.
- all input data to the process must be justified and subject to quality assurance.
- a components‘ susceptibility to different kinds of degradation mechanisms must be determined thoroughly. In the evaluation of susceptibility, all known degradation mechanisms or combined effects of them have to be taken into account and evaluated in a systematic manner, considering the influential parameters such as loads and other operating and environmental conditions in relation to design, dimensioning, and material properties of the components. The evaluation should be based on established susceptibility criteria, industry experience, available industry data bases, plant-specific experience, and research results.
- structural reliability models (SRMs) / probabilistic structural mechanics models and associated software, which are used to estimate failure probabilities, should be verified and validated.
- direct and indirect effects of all component failure modes (e.g., small leak, large leak, break) have to be considered. The impact of component failure on containment performance must also be evaluated. Due attention should be paid to low power and shutdown states. The consequences of component failure should be quantified or categorised with the help of PSA results or insights.
- the PSA should reflect the actual status and operational practices of the plant. It should use best estimate models and data, as opposed to conservative assumptions. Living Level 1 PSA is a prerequisite. A further prerequisite is that the models are sufficiently detailed in order to adequately support the application to RI-ISI. Ideally, living full scope Level 1 and Level 2 PSAs should be available. PSAs of lower scope can be used but areas not covered need to be taken into account, for example, by deterministic considerations or engineering judgement.

Other important aspects are that RI-ISI programmes must be living. Performance measurement strategies should be used to account for uncertainties in the analyses, to provide feedback and updating in due time, and to confirm the approach.

RI-ISI, as well as other ISI programmes, must be regularly updated to take the new information into account that could have an impact on the programme. The information from detected degradations, component failures, and damage analyses as well as enhanced knowledge on degradation mechanisms and influential factors should be incorporated into RI-ISI programmes continuously. Other changes such as PSA updates and plant design and operating changes should be considered periodically.

II.4 Overview of RI-ISI methods

The procedure to establish a RI-ISI programme includes several main steps: definition of scope (systems selected), division of piping systems into segments, failure analysis, failure consequence analysis, risk ranking of the items (i.e., segments or structural elements), safety significance categorisation of the items based on integrated decision making, structural element selection for inspection, establishing an inspection plan including inspection methods, frequencies and schedule, and defining a performance monitoring programme to trace the effectiveness of the RI-ISI programme and to provide feedback and updating. These steps are essentially common to all RI-ISI methodologies that have been developed.

Several RI-ISI approaches have been developed based on quantitative, semi-quantitative or qualitative methodologies, and can be described briefly as in [3]:

The WOG methodology makes extensive use of analytical models. The failure probabilities of piping segments are calculated by means of a Structural Reliability and Risk Assessment (SRRA) computer code, using probabilistic fracture mechanics methods. PSA provide a quantitative assessment of the consequence of failure. The initial risk ranking of the piping segments is based on the risk importance measure risk reduction worth (RRW). The final safety significance category, “high” or “low”, is determined by an expert panel in a process of integrated decision making. The expert panel combines all affected engineering disciplines. This method is a quantitative and relative one.

The EPRI methodology uses a more qualitative approach. Based on criteria derived from service experience and pipe failure data, each piping segment is checked whether it is susceptible to a certain degradation mechanism, and accordingly assigned to a rupture potential category (high, medium, and low). The consequence categorisation (high, medium, low, none) of each segment is based on the conditional core damage probability (CCDP) and conditional large early release probability (CLERP), connected with the segment’s most severe postulated failure mode. The CCDP is estimated from the plant-specific PSA for initiating events and derived from general PSA-based rules for loss of mitigating system events. In a matrix (“risk matrix”), the rupture potential categories are combined with the consequence categories to risk categories. Each pipe segment is assigned to a risk category. The risk categories are associated with three “risk regions”, high, medium, and low. As the EPRI methodology is designed to be process-driven, no expert panel is used. This method is a qualitative and absolute one.

The OMF-Structures[7] methodology was developed by EDF. It is conceived to be applied to the maintenance of piping outside the reactor coolant system of the 900 MW and 1300 MW reactor series. An application study is generic to an entire reactor series. ISI is included as being one measure of maintenance. OMF-Structures combines quantitative and qualitative methods as well as probabilistic and deterministic information and criteria in a systematic way. The quantitative evaluation uses risk importance measures. Though the use of structural reliability models (SRMs) is provided for to estimate pipe failure probabilities, up to now failure potentials have been estimated qualitatively. OMF-Structures support the optimisation of maintenance programmes with respect to safety, availability, and maintenance cost. These aspects, however, are decoupled, and this report considers the safety stakes only.

Det Norske Veritas (DNV), developed a quantitative procedure with software NURBIT (“Nuclear Risk Based Inspection Tool”), which is dedicated to piping systems prone to intergranular stress corrosion cracking (IGSCC). The piping failure probabilities are calculated for individual welds by means of a probabilistic fracture mechanics computer code, taking leak detection systematically into account. PSA provide a quantitative assessment of the consequence of failure. Risk ranking is made in terms of the CDF assigned to the failure of individual welds, i.e., in terms of an absolute risk measure. To determine the extent of inspection, however, a plant-specific relative scheme is suggested. The effect of inspection frequency is systematically included in the quantitative optimisation process. So far, no expert panel has been used. The software package NURBIT provides means to optimise the inspection programme with respect to minimum risk, inspection costs, failure costs, or radiation dose for the inspection personnel.

---

[7] OMF = Optimisation de la Maintenance par la Fiabilité (Reliability Centered Maintenance).

The STUK procedure has the perspective of full scope application. Consequently, at the starting point, all systems important to safety should be exposed to a selection procedure irrespective of the ASME class (1, 2, 3, or even non-class piping). Once the systems have been selected, the risk ranking procedure at the piping segment level is generally based on the EPRI scheme, but exhibits the following differences. The failure potential categorisation is somewhat more differentiated and more conservative: also degradation mechanisms other than flow accelerated corrosion such as IGSCC and aggressive thermal fatigue can be assigned a "high" rupture potential, whereas in the EPRI method they would always be categorised as "medium". Further, the STUK procedure makes full use of the plant-specific PSA to estimate the severity of failure consequences in terms of CCDP. The STUK procedure is not as prescriptive as the EPRI method and consequently uses, as an essential part, an expert panel to make the final integrated decisions.

The qualitative SKIFS 1994:1 scheme has been in place since 1988. It is based on the division of components and parts thereof into the control groups (A-C). The division shall be such that it takes into account the risks for nuclear fuel damage, discharge of radioactive materials, unintentional chain reactions, and the degradation of the other safety levels as a result of cracking or other degradation processes. In this respect, both the probabilities that such cracking or other degradation will occur in the specific component must be taken into account, as well as the possible resultant consequences. For the practical application of this approach a qualitative system is used where the division into the control groups is performed according to a risk matrix and assignment of a damage index and a consequence index to each component and parts thereof. The damage index gives a qualitative measure of the likelihood that a crack or other degradation will occur. The consequence index gives a qualitative measure of the likelihood that such degradation will result in nuclear fuel damage, damage to the reactor containment tightness, discharge of large amounts of radioactivity or other damage which could lead to ill health or an accident. This scheme makes no use of PSA results.

II.5 Comparison of methods

The existing qualitative methods are transparent and relatively easy to understand. They emphasise the most important features, i.e., susceptibility to or relevance of degradation mechanisms and severity of consequences. Assigning the items of the scope to broad range regions of risk and incorporating allowances for uncertainties, they conservatively discriminate "low" risk from "high" risk. Conservativeness or error in the analysis (under- or overestimating the risk) at one place do not influence the risk categorisation at other places, and the categorisation is stable against changes of the scope. As such, qualitative methods tend to be robust in and of themselves, provided they include suited decision criteria and are properly prescribed. Considering their instructions, however, it can not be expected that the different qualitative methods would yield similar results as regards the extent, the number, and the locations of inspection, when applied to the same plant and scope of piping.

The existing quantitative methods using structural reliability models provide better discernment and resolution than qualitative methods. In addition, they offer capabilities to tailor and optimise inspection strategies. The results, however, can only be correct, if the models, computing codes, and input data reflect the actual plant conditions. Some of the methods make only limited use of these possibilities. Other methods aim at fully exploiting the possibilities offered by the quantitative methodology. This includes quantifying the risk of each individual weld and ranking them in an order of descending risks against each other, considering the effect of leak detection on the failure rates also for the purpose of risk ranking, investigating the effect of inspection frequency and NDT system performance on risk, and optimising - on condition of risk reduction or neutrality - ISI programmes with respect to number and selection of inspection sites, inspection frequency, and NDT system performance. These differences in methodology can affect the outcome when applied to the same plant and scope of piping.

II.6 Overview of RI-ISI applications and pilot studies

RI-ISI is presently used in three countries, Spain, Sweden and United States (U.S). However, many other countries have performed pilot studies of different RI-ISI approaches to test methods and gain experience. Present RI-ISI applications and pilot studies are summarised in table 1.

From this table it can be seen that RI-ISI has been introduced in more than 50 percent of the U.S. plants. RI-ISI is non mandatory and can be used to as an alternative to ISI programmes based on the requirements in ASME Sect. XI. The Nuclear Regulatory Commission (NRC) has approved both the EPRI and WOG methodologies for this modification of the ISI programmes.

The prerequisite for the approval is that the proposed alternative represents an acceptable level of quality and safety compared to existing performance levels, which are given by ASME Sect. XI. Further, the five key safety principles of RG 1.174 for risk-informed changes of the Current Licensing Basis must be met. The performance level defined by the requirements of Sect. XI is acknowledged to provide reasonable assurance that public health and safety will be warranted. It should be noted, however, that the NRC-directed augmented inspection programmes for interganualar stress corrosion cracking (IGSCC) in BWRs and flow assisted corrosion (FAC), which overlap with the Sect. XI scope, remain unchanged. Such augmented inspections are credited and integrated to some extent, however, only piping made of IGSCC resistant material and contained in augmented IGSCC programmes may fully be subsumed in RI-ISI programmes. This means that the required equivalence of the RI-ISI schemes with Sect. XI only refers to piping that is recognised to be highly reliable. It should also be noted that the inspection frequencies (interval) and the inspection method (NDT) performance requirements essential have remain unchanged.

The NRC expects RI-ISI programmes to eventually be implemented at 99 operating nuclear power plants in the U.S. To date the NRC has received 69 RI-ISI submittals. Forty-nine (71%) of the submittals received by the NRC have been based on the EPRI methodology and the remaining twenty (29%) have used the WOG methodology. Of the 69 submittals received by the NRC, 52 have been approved and 17 are currently under review. The NRC anticipates that the receipt of the RI-ISI programmes for the remaining 30 plants will be submitted and approved over the next 2 years.

In Spain, the development in the U.S. towards RI-ISI has been closely followed. A joint pilot project of regulator, CSN, and the Spanish utilities (UNESA) was carried out with the objective to develop and validate an application guide for RI-ISI of piping systems. This guide, issued in 2000, follows the principles established in the NRC Regulatory Guides 1.174 and 1.178. RI-ISI is not a regulatory requirement but an option. Assessment and approval of applications by CSN is required. Several licensee applications for RI-ISI programmes, using the WOG methodology, have already been approved by CSN. These approved RI-ISI programmes are restricted to class 1 piping, but each Safety Evaluation Report issued on them by CSN contains a recommendation for extending the RI-ISI programme to a full scope application. CSN recommend full scope applications. In 2001, a Safety Guide on basic criteria for PSA applications was issued. A Safety Guide on RI-ISI is planned.

In Sweden RI-ISI is mandatory. The qualitative RI-ISI approach according to previous regulations and guidelines in SKIFS 1994:1 have been in place since 1988. It includes all known degradation mechanisms. No additional augmented ISI programs are therefore required. After a transition period of five years the SKIFS 1994:1 approach become mandatory in 1992 for all components and parts thereof, except reactor pressure vessels and some steam generators. For the reactor pressure vessel and for steam generator special rules apply. All 11 Swedish plants use this system as basis for the ISI programmes. However, the Swedish Nuclear Power Inspectorate, SKI, has recently approved a modified WOG methodology as an alternative for present ISI in one PWR. This has been assessed on the basis of the new regulation SKIFS 2000:2, which came into force on April 1, 2001. This new regulations allows the use of both qualitative and quantitative RI-ISI methods. The extent of inspections and the inspection interval shall be determined with respect to what is necessary with respect to assessed relative risks for core damage, release of fission products etc… Specific criteria for acceptance are not delineated, but assessment by SKI is required. SKI expects that two other PWRs will apply for the use RI-ISI programmes based on the modified WOG-methodology shortly. Swedish licensees have also indicated that they will apply for RI-ISI of reactor pressure vessels (RPV) in the next two years.

Also in Finland RI-ISI is mandatory, but only for new reactors. Existing plants may decide to continue with the present ISI programmes.

Pilot studies of different RI-ISI approaches to test the methods and to gain experience have been performed in Germany, Finland, France, Japan, Korea, Sweden, Switzerland and U.S. These pilot studies and used RI-ISI methodology are summarised in table 1.

II.7 RI-ISI experience so far

The concepts of RI-ISI has been successfully implemented in the U.S. and is now providing improved ISI that both reduce plant risks, reduces radiation exposure to inspection personnel, and reduces the costs imposed on industry. These benefits have been achieved as the end of a decade-long period of development and implementation beginning with NRC policies to endorse and support risk-informed regulation and industry efforts to reduce plant operating costs. During this period the NRC and industry worked effectively to bring risk concepts into the ASME code.

Experience from applications of RI-ISI in U.S. nuclear power plants has been compiled in a recent ASME white paper [4]. This is based on a review and analysis of the result of almost 50 approved plant-specific RI-ISI applications. The review covered 17 class 1, 27 class 1 & 2, and five class 1, 2, 3 & non-class (“full scope“) applications.

The number of welds contained in the scope of class 1 and 2 is typically between 1500 and 3000. A typical RI-ISI programme for class 1 and 2 piping comprises about 100 welds. Compared to ASME Section XI programmes, RI-ISI programmes typically bring about reductions in the number of inspection sites of approximately 80 %, the spread ranging from 45 % to 84 %. If there are extensive augmented programmes, it can happen that only few non-augmented programme welds are determined by the risk-based procedure as being safety-significant.

For class 1 systems, resulting sample sizes of RI-ISI programmes are at or below 10 % (ASME Sect. XI: 25 %). Class 2 piping tends to be at 0.1 to 2.0 % range (ASME Sect. XI: 7.5 %). Risk-informed sample sizes in break exclusion regions are around or below 10 %. It should be noted that there are ongoing discussions on a minimum class 1 sample size. Only very few inspection sites were identified in class 3 and non-class piping, most of them in the WOG pilot study Surry 1. The two non-pilot full scope applications contained in the review, did not identify any class 3 or non-class locations to be inspected.

Similar results have been reported from the application of RI-ISI in Spanish and Korean plants [2]. However, some of Spanish plants have experienced a smaller reduction due to the fact that more welds have been included in the RI-ISI programs for defence-in-depth reasons.

Application of the qualitative RI-ISI approach in Sweden has also been successful. Only a small portion (2%) of occurred cracking and other degradation have lead to leakage. More than 90 % of the degradation has been detected by ISI. Performed pilot studies with quantitative RI-ISI methods indicate that this good result can be maintained despite reductions in the inspection extent.

II.8 Further evaluations and developments of RI-ISI methodologies

Further evaluations and developments of RI-ISI methodologies were addressed in the IAGE RI-ISI questionnaire [1] and were discussed at the OECD Workshop on RI-ISI and NDT qualification [2]. Theses aspects have also been discussed in other international and national forum, e.g. NRWG and the industry group ENIQ and ASME Task groups.

Identified needs of further evaluations are:

- Comparative RI-ISI method performance study by applying several of the existing qualitative and quantitative methods to the same specific scope of piping in one or two plants, and comparing the results in terms of the extent, the number and the locations of inspection sites.
- Evaluation of differences in ISI selection when applying a quantitative method to a specific scope of piping in a plant with and without leak detection, and comparing the results in terms of the extent, the number and the locations of inspection sites as well as resulting requirement on the leak detection system capabilities and demands on operator actions.
- Further benchmarking and validation of existing structural reliability models (SRMs) / probabilistic structural mechanics models and associated software.
- Evaluation of the influence of different assumptions about probability-of-detection (POD) curves and independent versus dependent inspections on calculated failure rates.

Identified needs of further developments and co-operation are:

- Continued support to the international degradation and damage data base OECD Piping Failure Data Exchange (OPDE).
- Joint actions to establish consensus criteria for component susceptibility to different kind of degradation mechanisms.
- Continued exchange of experience from RI-ISI applications and pilot studies
- Joint actions to develop and extending RI-ISI methodologies to other components and safety related structures.

Table 1. Overview of used RI-ISI applications and performed pilot studies

Country	RI-ISI application					RI-ISI Pilot studies			Comments
		No. of plants	Scope	Used methods	Regulatory requirement/guidance		Scope	Studied methods	
Belgium	No	-	-	-	-	No	-	-	No specific plans for RI-ISI implementation
Canada	No	-	-	-	-	No	-	-	Some risk-informed applications for ISI of specific components
Czech Republic	No	-	-	-	-	No	-	-	No specific plans for RI-ISI implementation
Germany	No	-	-	-	-	Yes	Some piping systems	WOG/ NUREG 1661	No specific plans for RI-ISI implementation
Finland	No	-	-	-	YVL 3.8, YVL 2.8	Yes	Some piping systems	STUK	RI-ISI mandatory for new plants. No specific plans for existing plants
France	No	-	-	-	-	Yes	Some piping systems	OMF-Structures	No specific plans for RI-ISI implementation
Hungary	No	-	-	-	-	No	-	-	No specific plans for RI-ISI implementation
Japan	No	-	-	-	-	Yes	Some piping systems	EPRI and WOG	No specific plans for RI-ISI implementation
Korea	No	-	-	-	Modified USNRC Reg.guide 1.174, 1.78	Yes	Class 1 and 2 piping systems	WOG	Plans to introduce RI-ISI applications in several plants
Spain	Yes	2	Class 1 and 2 piping systems (including. augmented. ISI)	WOG	CSN 01, Guide RI-ISI-02	Yes	Some class 1, 2 and 3 piping systems	WOG	Plans for further RI-ISI applications
Sweden	Yes	11	All piping systems (including augmented. ISI)	SKIFS 1994:1 and modified WOG (1 plant)	SKIFS 2000:2	Yes	Some piping systems	WOG and NURBIT	RI-ISI mandatory. Plans for further quantitative RI-ISI applications. RI-ISI will be studied. For RPV.
Switzerland	No	-	-	-	-	Yes	Some piping systems	EPRI and WOG	No specific plans for RI-ISI implementation

Country	RI-ISI application					RI-ISI Pilot studies			Comments
		No. of plants	Scope	Used methods	Regulatory requirement/guidance		Scope	Studied methods	
United Kingdom	No	-	-	-	-	No	-	-	Some qualitative risk-informed application for ISI of specific components
Untied States	Yes	52	Class 1, 2 and 3 piping systems. Full scope or partial scope (augmented ISI still apply)	EPRI and WOG	USNRC Reg. guide 1.174, 1.178, SRP 3.9.8	Yes	Class 1, 2 and 3 piping systems. Different scope.	EPRI and WOG	Non mandatory. All plants in US are however expected to introduce RI-ISI. Development work on RI-ISI for PRV and containment are ongoing.

III NON-DESTRUCTIVE TESTING (NDT) QUALIFICATION

III.1 Development of NDT qualification strategies

The effectiveness of ISI in reducing risk depends on the reliability of the NDT system applied. The need to qualify NDT systems for pre- and in-service inspection has therefore been recognised to a greater or lesser extent for many years in many countries engaged in nuclear power generation.

Qualification of procedures and personnel for NDT of nuclear plant components has been required by U.S. regulations from the beginning of the U.S. commercial nuclear power industry. Accordingly, the responsibility for NDE qualification rests with the plant owner. This requirement, however, is general, and does not give specific requirements or criteria for qualification. In the U.S., qualification programs for specific components have been developed and are now available to enable the plant owner to comply with this obligation in a uniform way across the industry. For certain ultrasonic testing (UT) required by ASME Section XI, Appendix VIII to Section XI provides specific requirements for demonstrating performance.

The concept of the ASME rules for qualifying procedures, equipment and personnel for ultrasonic examinations was initiated in 1975 by the Section XI NDE group and reemphasized in 1982 by the inability to detect intergranular stress corrosion cracking (IGSCC) in the primary piping at the Nine Mile Point Power Plant. This incident caused the NRC to mandate specific performance capability demonstrations of the ultrasonic systems used or planned to be used to examine welds in BWR recirculation system piping. Specific actions were required in the NRC Inspection and Enforcement Bulletin (IEB) 82-03 and IEB 83-02. Within this context, the Electric Power Research Institute's (EPRI) NDE Centre began to arrange programmes for the industry capability demonstrations [4, 5].

The concerns about ultrasonic NDT unreliability were, however, not restricted to manual ultrasonic examination of IGSCC susceptible piping welds. Discouraging defect detection and sizing performance observed during studies coordinated by the U.S. Pressure Vessel Research Committee and during the PISC programme, as well as the equally discouraging performance measured during the NRC sponsored Pipe Inspection Round Robin Trials (PIRR/MRR), led to the establishment of an ASME Section XI Ad Hoc Task Group in late 1984. The task of this Ad Hoc Group was to develop input for recommended Code rules for the administration and control of NDT system qualification programmes, as well as control of NDT performance of Section XI applications. The Ad Hoc Task Group proposed a Mandatory Appendix VII to Section XI. This document was formally approved for submission to the Section XI Subgroup on Non-destructive Examination (SGNDE) in February 1986. Subsequently, the SGNDE revised and restructured this document into two separate proposed Mandatory Appendices; Appendix VII entitled *"Qualification of Non-destructive Examination Personnel for Ultrasonic Examination"*, and Appendix VIII entitled *"Performance Demonstration for Ultrasonic Examination Systems*". Appendix VII was approved and first published in the 1988 Addenda to the 1986 Edition of Section XI, and Appendix VIII was published in the 1989 Addenda to the 1989 Edition.

The modification to Section XI of the ASME XI to include formal requirements for what it terms performance demonstration has resulted in a large programme by the licensees in the U.S. to provide the appropriate procedures, facilities and infrastructure. This programme is known as the Performance Demonstration Initiative (PDI).

Also European regulators and licensees had concerns about NDT unreliability. It was be recognised that all part of an NDT system affects its performance. Equipment, techniques, procedures as wells as NDT operator must therefore be included in the assessment of the NDT effectiveness. In November 1992 the Nuclear Regulatory Working Group (NRWG) decided to set up a Task force on qualification of NDT system for pre- and in-service inspection of light water reactors. The task was to

- agree on the philosophy and principles governing the qualification of techniques, equipment, software, procedures and personnel for NDT to be used for inspection of structural components that are important to safety in nuclear power plants; and
- to establish a common view on essential aspects of NDT qualifications.

The result has been published in the report "Common position of the European regulators on qualification of NDT systems for pre- and in-service inspection of light water reactor components" [7].

In parallel, the European nuclear power industries had set up a working group, the European Network for Inspection Qualification (ENIQ), to discuss and agree on how to perform inspection qualifications. In 1995 ENIQ finalised their first version of "European methodology for qualification of non-destructive tests". A second version was then published in 1997. This second version is in relatively close agreement with the principles given in the regulators' common position document. With these two basic documents a platform thereby had been established for the further development of qualification strategies in the European countries.

III.2 NDT-qualification requirements and applications

Since the introduction ASME Appendix VIII and the European qualification methodologies formal NDT qualification requirements have been introduced or are on the way of being introduced in most countries engaged in nuclear power generation. An overview and present NDT-qualification applications are given in table 2.

NDT qualification requirements are either in the form of regulations or regulatory guides or in the form of individual plant licence conditions. Transition periods still apply in some countries, but the requirements will become fully effective in the near future. Where formal requirements not are regulatory practice, there are clearly expressed regulatory expectations of NDT qualifications. This is for example the situation in the United Kingdom (UK).

In addition to mandatory qualifications many non-mandatory qualifications are performed in many countries. This is for example the situation in U.S. ASME Appendix VIII, by definition, addresses only those ultrasonic examinations required by the ASME code. Many other, non-code, examinations are performed to address specific components, specific safety related issues, or to address economic or maintenance related situations. Each of these has developed qualification approaches to address specific requirements. For example, the Boiling Water Reactor Vessels and Internals Project (BWRVIP) has developed inspection requirements for the BWR reactor vessel, internal structures, and selected piping systems. The Steam Generator Management Project (SGMP) has developed a comprehensive qualification program for techniques and data analysts for inspecting steam generator tubing. A relatively new organization, the Materials Reliability Project (MRP), is focusing on PWR materials issues such as thermal fatigue in piping, PWR internals, PWR vessels, and Alloy 600/82/182 materials such as found in CRDM head penetrations and piping welds. Each of these groups of utility representatives has defined qualification objectives, requirements, criteria, schedules, and also monitor the implementation of the qualification program.

Table 2 Overview of NDT qualification requirements and applications

Country	NDT requirements and applications				
		Scope (components and parts)	**NDT-methods that have to be qualified**	**Partial or full system qualification**	**System qualification methodology**
Belgium	yes	Class 1-2 components	Ultrasonic (UT), eddy current (EC)	Full system	Both ASME /PDI and European methodologies
Canada	partly	-	-	Only personnel	-
Czech Republic	yes	Some safety class components	UT, EC	Full system	European methodology
Germany	partly	-	-	Only personnel	-
Finland	yes	Class 1-2 components	UT, EC	Full system	European methodology
France	yes	Class 1-2 components	All NDT methods	Full system	European methodology
Hungary	partly	-	-	Only personnel	-
Japan	partly	-	-	Only personnel	-
Korea	yes	Class 1-3 components	UT, EC	Full system	ASME/PDI methodology
Spain	yes	Class 1-2 components	UT, EC	Full system	Both ASME /PDI and European methodologies
Sweden	yes	Control group A and B (see page 9)	All NDT methods	Full system	European methodology
Switzerland	yes	Some safety class components	UT, EC	Full system	European methodology
United Kingdom	yes	Some safety class components	UT, EC (and other surface methods)	Full system	European methodology
Untied States	yes	Class 1-2 components	UT	Full system	ASME/PDI

III.3 NDT-qualification experience

Implementation experience to date indicates that NDT qualifications have contributed to more reliable NDT systems for ISI. Qualified NDT-systems, in general, performs well. There is confidence in their capability and reliability. Decision making during the NDT process have become more transparent and convincing.

These increases in performance have however not come without cost. Inspection companies invested considerable effort to improving their procedures and equipment and training of staff to meet these new objectives. Many previously acceptable procedures had to be rewritten, both to improve their performance and to include much more specific description of the decision logic to enable meaningful qualification. Prior to implementation of qualification by performance based demonstration, much of the decision logic was not described explicitly in procedures, but was left to the interpretation of the examiner. Qualification principles applied in many countries require that the critical decision logic be described in full detail in the procedure and that this logic be followed rigorously during the performance demonstration. The logic is documented in the qualification record, and is available to the licensee who can then ensure that this same logic in applied in the actual ISI. The introduction of qualification is also bringing detailed documentation of procedure capability and applicability. The capability and scope of procedures applicability is now documented to a higher level of detail than ever before in the industry. The qualification dossier now contains details such as weld shape, surface roughness, weld crown contours, weld design, and accessibility that enable plant owners to evaluate the examination and the qualification dossier in advance to ensure that qualified procedures are available. Thus, plant owners can now be confident that ISI procedures can effectively address specific plant conditions.

This unprecedented level of detail about procedure applicability has had another outcome that was not predicted at the beginning of qualification. NDT procedures for some welds that had been examined for many years are now possibly not qualified because one or more of the limitations documented in the qualification are encountered. For example, procedure qualification documents now explicitly define the range of weld crown conditions for which the procedure is qualified.

Implementation experience to date also shows that there are problems to be solved before the chosen qualification approaches will fully produce effective NDT systems and reliable inspections in a cost-effective manner. The concept of technical justifications, which is essential in the European methodology, is generally used as an important part of the qualification process. In some situations, qualifications are also mainly or even exclusively based on technical justifications. However, in many countries it still seems to be difficult for many licensees and their NDT companies (vendors) to produce adequate and credible such justifications. Analysis of essential parameters (variables) and justifying the extent of practical demonstrations by means of supporting evidence are examples of observed difficulties. The situation is gradually improving as more and more qualifications are accomplished.

Another area where further improvements and developments are needed relates to the production of test blocks with realistic defect simulations. The representation of defects in the qualification test blocks is a key point in any practical assessment. The response of the defects used, with respect to the actual NDT system, must therefore adequately represent the response of the expected or observed real defects. However, experience to date shows that it not is an easy task to establish the representation of proposed defect simulations for a particular qualification exercise. There consequently is a need for increasing the knowledge and producing additional supporting information.

IV CONCLUSIONS AND RECOMMENDATIONS

IV.1 Conclusions

Major changes of ISI approaches have been introduced during the last decade. The evolution of PSA methodology has provided an enhanced understanding of the consequences of component failures. This progress together with the accumulation of plant operating experience and the development of probabilistic structural mechanics methods have found basis for RI-ISI.

The concepts of RI-ISI have successfully been implemented in several countries and are now along with NDT qualification providing improved ISI that both reduce plant risks and radiation exposure to inspection personnel. These benefits have been achieved at the end of a long period of development and implementation.

The concept of NDT qualification has been implemented in most countries. Implementation experience to date indicates that NDT qualifications have contributed to more reliable NDT systems for ISI. Qualified NDT-systems, in general, performs well. There is confidence in their capability and reliability. Decision making during the NDT process have become more transparent and convincing.

Implementation experience to date and results of pilot studies shows however also that further evaluations and developments of RI-ISI and NDT qualification approaches are needed.

IV.2 Recommendations

Based on the questionnaire [1] and discussions at the OECD Workshop on RI-ISI and NDT qualification [2] the following recommendations are made:

<u>Further evaluations</u>

- Comparative RI-ISI method performance study by applying several of the existing qualitative and quantitative methods to the same specific scope of piping in one or two plants, and comparing the results in terms of the extent, the number and the locations of inspection sites;
- Evaluation of differences in ISI selection when applying a quantitative method to a specific scope of piping in a plant with and without leak detection, and comparing the results in terms of the extent, the number and the locations of inspection sites as well as resulting requirement on the leak detection system capabilities and demands on operator actions;
- Further benchmarking and validation of existing structural reliability models (SRMs) / probabilistic structural mechanics models and associated software;
- Evaluation of the influence of different assumptions about probability-of-detection (POD) curves and independent versus dependent inspections on calculated failure rates.

<u>Further developments and co-operation</u>

- Continued support to the international degradation and damage data base OECD Piping Failure Data Exchange (OPDE);
- Cooperative actions to establish consensus criteria for component susceptibility to different kind of degradation mechanisms;
- Continued exchange of experience from RI-ISI applications and pilot studies;

- Cooperative actions to develop and extending RI-ISI methodologies to other components and safety related structures;
- Continued exchange of experience from NDT qualifications including developments of techniques for production of test blocks with realistic defect simulations.

REFERENCES

[1.] NEA/CSNI/R(2005)3 Review of Risk-Informed In-Service-Inspection (RI-ISI) and Non-destructive Testing (NDT) Qualification in OECD-NEA member countries- Responses to the questionnaire

[2.] NEA/CSNI/R(2004)9 Proceedings of the CSNI Workshop on "International developments and cooperation on Risk-Informed In-Service-Inspection (RI-ISI) and Non-destructive Testing (NDT) Qualification" held in Stockholm, Sweden on 13-14 April 2004 and hosted by SKI.

[3.] Report on the regulatory experience of risk-informed in-service inspection of nuclear power plant components and common view. EUR 21320 EN. European Commission. August 2004.

[4.] P. O'Regan and K. Hall, "A Blended Approach To Defining Examination Requirements", ASME Section XI Working Group on the Implementation of Risk-Based Examinations, Report No. 2002-02A-01, Revision 0, February 2004.

[5.] C. D. Cowfer, O.F. Hedden, "Overview of the ASME Section XI Code Relating to NDE and Ultrasonic Examination Performance Demonstration". Journal of Pressure Vessel Technology, May 1991, Vol 113/170.

[6.] J. C. Spanner et al., "Qualification Process for Ultrasonic Testing in Nuclear In-service Inspection Applications". NUREG/CR-4882. US Nuclear regulatory Commission, March 1990.

[7.] Common position of European regulators on qualification of NDT systems for pre- and in-service inspection of light water reactor components. EUR16802. European Commission, Directorate-General XI, Environment, Nuclear Safety and Civil protection. 1997.

[8.] European Methodology for Qualification of Non-Destructive Tests: second issue. EUR17299. ENIQ Report 2, European Commission 1997.