Plenary Session
The Current International Position on Major Inspection Concerns

European Trends in NDE for the Nuclear Industry
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ABSTRACT

In-service inspection by non-destructive testing continues to be an issue high on the agenda, not least shown by the interest in this conference. With ageing plants, life-extensions and opening of the electricity market it is as important as ever to maintain high safety and reliability of plants. This paper will review some of the trends and give an update on recent developments that can be observed in Europe.

Although “NDT qualification” is reaching maturity in Europe it is still seeing some significant developments. Within the European Network for Inspection and Qualification – ENIQ – developments continue on both areas of inspection qualification and risk-informed in-service inspection (RI-ISI).

In addition, a large international benchmark study of various RI-ISI methodologies, under the auspice of JRC and OECD, with more than 20 participating organisations, was finalised.

As Qualification Bodies in Europe have been established in most countries, significant experience has been gained over the years and the wish for stronger cooperation has been expressed. Meanwhile, the “3rd International Workshop of Qualification Bodies”, jointly organised by JRC and IAEA was held in October 2008 in Vienna, Austria.

This paper updates the status report on ENIQ, which was presented at the 6th International Conference on NDE in Relation to Structural Integrity for Nuclear and Pressurized Components in October 2007 in Budapest, Hungary [14].

OVERVIEW OF ENIQ AND PROGRESS

History

ENIQ was set up in 1992 as the importance of the issue of qualification of NDE inspection systems (procedures, equipment and personnel) used in ISI programmes for nuclear power plants was identified. Driven by European nuclear utilities and managed by the European Commission Joint Research Centre (JRC) in Petten, ENIQ was meant to be a network in which the available resources and expertise could be pooled at European level. The parties involved in ENIQ also recognized that harmonization in the field of codes and standards for inspection qualification would represent important advantages for all, with the ultimate goal of increasing the safety of European nuclear power plants.

A significant milestone was reached with the publication of the first issue of the European Methodology for Qualification of non-destructive tests in 1995. The European Qualification Methodology Document (EQMD) contained guidelines for the qualification of non-destructive tests. Qualification as defined in that document is a combination of technical justification, which involves assembling mainly the following supporting evidence for test capability and test piece trials using deliberately defective test pieces.

- results of capability evaluation exercises
- feedback from site experience
- applicable and validated theoretical models
- physical reasoning)

This document was the first to be published in Europe on this issue and contained a number of innovative proposals such as the use of technical justification, the separation between
procedure/equipment and personnel qualification and the use of non-blind trials for procedure and equipment qualification.

In April 1996 the European Regulators issued a common position document on qualification of NDT systems for pre- and in-service inspection of light water reactor components [1]. This official report of the Nuclear Regulator Working Group (NRWG) considered also the essential elements of the European Methodology and is, in general, in good agreement with it. There were two major differences: firstly the European regulators discussed the issue of inspection qualification in a wide context of safety and secondly they placed different emphasis on the different elements constituting inspection qualification.

Since the publication of the EQMD the issue of inspection qualification was discussed widely both at national and international level and some evolution in thinking occurred. The Steering Committee of ENIQ thus decided to conduct a first pilot study to explore ways of applying the European Methodology for inspection qualification to a specific component. A number of important lessons were learned from this pilot study. All this led the Steering Committee of ENIQ to issue a second version of the EQMD, which was approved by the Steering Committee of ENIQ in February 1997.

In 1999, the final report of first pilot study was published. Between 1999 and now, ENIQ produced a series of 10 Recommended Practices, i.e. documents supporting the high-level EQMD with more specific guidance, see Table 1.

Based on the results of the second ENIQ pilot study and based on experience feedback from applying the ENIQ methodology in Europe the Steering Committee decided to revise the European Methodology Document. This third issue of the EQMD [2] has been produced by ENIQ TGQ, and was approved for publication by the ENIQ Steering Committee. The main changes from Issue 2 are as follows:

- Updating of the foreword to reflect the much more mature status of qualification in Europe prevailing today
- Adding references to the text citing existing supporting Recommended Practices wherever possible
- Rewriting of Appendix 3 to summarise the content of Recommended Practices which have actually been issued
- Editorial changes and changes to clarify the text.

No changes to the actual principles of the European Methodology have been made.

In 1999, ENIQ also recognized the importance of addressing at European level the issue of optimising inspection strategies on the basis of risk. Traditionally, strict regulations and codes specify the locations, frequency and methods of inspection based primarily on the type and safety class of the component. However, it has been recognized that many resources have often been spent inspecting sites of negligible risk for plant safety. On the other hand, practical experience and the use of probabilistic safety assessments have demonstrated that failures with high risk significance can occur at locations not covered by the traditional inspection programme. As the costs of qualifying and performing such effective inspections are very high, the effort must be targeted at the most risk-significant locations. For this reason, in 1996 ENIQ set up a sub-group in order to homogenize the different activities on RI-ISI for nuclear reactor safety and to develop a harmonized European approach to RI-ISI.

At the end of 2001, ENIQ members emphasized the need to strengthen the risk-related activities and to promote the full integration of RI-ISI into ENIQ. In connection with the reorganization of ENIQ working groups, this became Task Group on Risk (TGR). At the kick-off meeting of TGR, it was decided that the task group aims at establishing a common European framework on RI-ISI.

The European Framework Document for Risk Informed In-Service Inspection [3] is intended to serve as guidelines for both developing own RI-ISI approaches and using or adapting already established approaches to European environment taking into account utility-specific characteristics and national regulatory requirements.
Recent inspection qualification activities

A key achievement of ENIQ has been the issue of the European Qualification Methodology Document [2], which has been widely adopted across Europe. This document defines an approach to the qualification of inspection procedures, equipment and personnel based on a combination of technical justification (TJ) and test piece trials (open or blind). The TJ is a crucial element in the ENIQ approach, containing evidence justifying that the proposed inspection will meet its objectives in terms of defect detection and sizing capability. A Qualification Body reviews the TJ and the result of any test piece trials and issues the qualification certificates.

In order to test the European Methodology, two pilot studies have been conducted in which qualifications have been performed for inspections of mock-ups simulating specific plant components. The First Pilot Study, on an austenitic pipework weld, is complete and has been reported elsewhere (see e.g. [4]). A Second Pilot Study has been completed, for an automated ultrasonic inspection of a clad ferritic BWR-type nozzle-to-shell weld [5]. The aim of this study was to explore the potential of a TJ to reduce or remove the need for full-scale practical trials on mock-ups.

In this Second Pilot Study, a full-scale test piece containing artificially inserted defects was made to simulate the real component. A specification was drawn up of the defects which the inspection was required to find, and an automated ultrasonic inspection was designed to detect them. A TJ [6] was written which predicted whether the designated inspection would be successful in detecting the specified defects. The evidence in the TJ came mainly from physical reasoning, theoretical modelling and results from previous work. The effect of the cladding was quantified partly using new experimental measurements on a clad “parametric studies” block, and partly from existing evidence in the literature. The predictions of the TJ were then compared with experimental measurements taken on the defects in the test piece – these measurements simulated the actual inspection of the component.

This exercise was largely successful in demonstrating that TJs have the potential to predict the outcome of specific inspections and thus to reduce or remove the need for large-scale test pieces in qualification. However, the extent to which this can be done in practice will vary from case to case, depending on the difficulty of the inspection, the availability of relevant existing data and the ability and resources to generate new data which can be used in the TJ. The exercise also showed the value of theoretical modelling, but emphasised the importance of only using models which have been experimentally validated and using them within their regimes of validity, as reported in the final report of the ENIQ 2nd Pilot Study [7].

Both the first and second pilot study, as well as the experience feedback from field-qualifications, led to a number of Recommended Practices and their revision.
Meanwhile, the European Qualification Methodology Document is supported by nine issued Recommended Practices (Table 1), covering various aspects of qualification in more detail. All these documents provide guidance on conducting qualification, while retaining the flexibility to allow detailed variations in implementation between different countries.

Recent developments on Recommended Practices include a new issue of RP1 on influential and essential parameters, and the first issue of RP8 on qualification levels and approaches. A brief overview of these developments is given here.

RP1 was revised to simplify and clarify the recommended approach to the treatment of influential and essential parameters, following feedback from users on applying Issue 1. This is a good example of how the Recommended Practices are regarded as “living documents”, to be reviewed periodically in the light of feedback from users.

The influential parameters are those parameters (for example defect orientation or probe beam angle) which can potentially affect the outcome of an inspection, while the essential parameters are those which could actually affect the outcome of a specific inspection in such a way that the inspection would no longer meet its objectives.

The main changes from Issue 1 of RP1 are:

- Combining the procedure and equipment parameter groups into a single inspection system group.
- Clarification that the non-inclusion of parameters which are clearly non-essential need not be justified in the TJ.
- Removal of the distinction between essential inspection system parameters which are “fixed within a tolerance” and those “covering a range”. Instead these parameters are categorised

<table>
<thead>
<tr>
<th>RP number</th>
<th>Title</th>
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<td>Jun 05</td>
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<td>Jul 98</td>
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<td>EUR 18100 EN</td>
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<td>Guidelines for the design of test pieces and conduct of test piece trials</td>
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<td>The use of modelling in inspection qualification</td>
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<td>Recommended general requirements for a body operating qualification of non-destructive tests</td>
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<td>Qualification levels and approaches</td>
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<td>Jun 05</td>
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<td>RP9</td>
<td>Verification and validation of structural reliability models and associated software to be used in risk-informed in-service inspection programmes</td>
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<td>May 07</td>
<td>EUR 22228 EN</td>
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<td>RP11</td>
<td>Guidance on expert panels in RI-ISI</td>
<td>Jun 08</td>
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<td>ENIQ Glossary</td>
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Table 1. List of ENIQ Recommended Practices
(available on the ENIQ website http://safelife.jrc.ec.europa.eu/eniq/)
into so-called “Set 1” parameters (those which particularly affect the outcome of the inspection) and “Set 2” parameters (those which only affect the outcome if they differ substantially from their chosen values).

- Confirmation that the essential parameters should be listed in a table in the TJ, but with clarification of how each type of parameter (Input, Inspection System Set 1, and Inspection System Set 2) should be addressed.

RP8 is a Recommended Practice on qualification levels and approaches. It recognises that some countries or organisations might wish to introduce the concept of different qualification levels, depending on the assurance required that the inspection would attain its objectives in demonstrating structural integrity. One method of setting the qualification level is using a risk-informed methodology, and the RP provides some guidance in doing this.

The qualification level in turn acts as one of the inputs in determining the qualification approach, that is, the range of qualification activities needed to achieve the desired qualification level. This qualification approach will depend on the difficulty or novelty of the proposed inspection as well as the qualification level itself. The chosen qualification approach will affect various aspects of qualification such as the realism of the test pieces used (full-scale, simplified, or flat plates), the requirements for the Qualification Body and the QA arrangements.

Furthermore, RP2 and RP3 underwent revision by TGQ recently, merging the two documents into a single RP, which will be called “Strategy and Recommended Contents for TJs”. The final draft of a new RP10 on personnel qualification was finalised and approved by TGQ, too.

In a survey on harmonisation of nuclear safety among EU member states, the Working Party on Nuclear Safety” (working under the European Council) concluded that the ENIQ documentation is widely used throughout Europe. Further, the usefulness of the documentation was recognized by WENRA in their recent report on reactor safety reference levels [13].

Examples of recent developments in qualification in European countries

The ENIQ approach to qualification has now been widely adopted across Europe, including the new EU members, and many successful qualifications have been completed. Several countries have set up their own qualification bodies. ENIQ members regularly report to ENIQ Steering Committee meetings on developments in their individual countries under a standing item on the agenda. Recent reports include:

- An update on qualification work in Belgium on RPV and primary circuit welds, including Inconel safe-end welds.
- An update on the extensive qualification programme for VVER components underway in the Czech Republic.
- 10-15 qualifications underway in Finland, together with preparation of qualification of preservice inspections at Olkiluoto 3, the new European Pressurised Reactor power station now under construction.
- Contacts initialised between Sweden and Finland to promote the mutual recognition of inspection qualification and intensify bilateral collaboration.
- A pilot study to investigate the feasibility of introducing the ENIQ qualification methodology in Germany has been successfully completed.
- A review of its activities by the Swedish Qualification Centre, which has now been in existence for 10 years.
- A 10-year timescale introduced in Switzerland in 2003 for the implementation of qualification.
- A qualification of the ultrasonic inspection of studbolts in boiler closure units at AGR power stations in the UK; also the qualified inspections of the Sizewell B RPV at the end of the first 10 years of operation.
Recent risk-informed in-service inspection activities

As mentioned above, ENIQ Task Group on Risk (TGR) has published the European Framework Document for Risk Informed In-Service Inspection [3], which forms a basis for its current activities. It might be worth mentioning that this document is one of the basic requirements when RI-ISI was developed in Finland for TVO3 (EPR under construction). Following the publication of the Framework Document TGR is currently working on several RI-ISI related issues to develop Recommended Practices and discussion documents in support of a more detailed harmonisation in Europe:

- Defence in depth issues
- Verification and validation of structural reliability models (SRM) & codes
- Guidelines for expert panels
- Interaction between RI-ISI and inspection qualification
- Guidelines for use of PSA in RI-ISI
- Expert elicitation for degradation mechanisms
- RI-ISI application for internals, RPV
- Sensitivity and uncertainty analyses (both structural reliability models and PSA)
- Criteria, risk importance measures / risk acceptance criteria
- Justification of partial scope RI-ISI application
- The applicability of Code Case N716 in EU

A basic regulatory requirement when introducing RI-ISI is to maintain defence-in-depth. In order to elaborate its view on this issue, TGR has published “ENIQ TGR Discussion document on the role of ISI within the philosophy of defence in depth” [9]. The report discusses the role of the ISI programme (and connected activities) within the entire reactor safety programme, with special focus on the defence-in-depth philosophy for reactor safety. More specifically, the report deals with such issues as the tools and the processes used to determine pipe break frequencies, and gives a perspective on pipe break frequency's contribution to core damage frequency.

Following up on the FP5 project NURBIM, TGR members have elaborated and published ENIQ Recommended Practice 9: Verification and Validation of Structural Reliability Models and Associated Software to Be Used in Risk-Informed In-Service Inspection Programmes, see Table 1. Structural Reliability Models are commonly used to evaluate failure probabilities in the development of RI-ISI programmes. RP9 summarises the Verification and Validation requirements that should be met in order to be suitable for such purposes:

- The basic programming can be shown to have suitable quality assurance documentation.
- The scope, analytical assumptions and limitations of the modelling capability are well defined.
- The analytical assumptions are well grounded and based on theory that is accepted as representative of the situations considered by the given SRM.
- The model is capable of reproducing the data on which its analytical assumptions are based and examples are provided that can demonstrate its general agreement with the available experimental data.
- Attempts have been made to show how the model compares with the world or field data.
- The model has been benchmarked against other SRM models within the same field or scope and possible differences are adequately explained.

The Framework Document [3] recommends the use of Expert Panels (EP) to review the selection of safety-significant sites before the inspection programme is finalised. However, more detailed guidance was not provided and to this end, TGR is developing a soon to be published ENIQ Recommended Practice on the subject. This ENIQ Recommended Practice is supposed to assist a user involved in a RI-ISI application on how to form, plan and prepare, conduct, and document an expert panel whose final goal is making decisions concerning the inclusion or exclusion of sites from the risk-informed inspection programme. It also covers the role, responsibilities and composition of an EP. The development of guidelines for the expert panel process in this area has also been recommended by
the Nuclear Regulatory Working Group, who explicitly advocates the use of Expert Panels in its report on the regulatory experience of RI-ISI [10].

In a joint project between TGR, JRC and the OECDs Nuclear Energy Agency (NEA), some 20 partners (utilities, regulators, R&D, vendors…) have performed a unique benchmark of various RI-ISI methodologies, applied to the same set of four piping systems of a Swedish PWR. The general objective was to identify the impact of such methodologies on reactor safety and how the main differences influence the final result, i.e. the definition of the RI-ISI programme.

The project was divided into five application groups and four evaluation groups. The application groups were using the following methodologies on the defined set of four piping systems:

- Westinghouse Owners Group, both in original version, and with amendments/changes required by the Swedish regulatory body;
- SKIFS 1994 (a previous qualitative methods previously required in Sweden);
- EPRI methodology;
- Code Case N-716;
- And, as a comparison, the ASME Section XI approach, including augmented programme.

The four Evaluation Groups were each studying the following aspects:

- Scope of application
- Failure Probability Analyses
- Consequence analyses
- Risk ranking, classification and selection of segments/sites, definition of inspection programmes

A more detailed description of TGR work may be found in [8], these proceedings.

QUANTIFICATION OF NDE RELIABILITY

The output from the European inspection qualification process is generally a statement concluding whether or not there is high confidence that the required inspection capability will be achieved in practice, for the specified inspection system, component and defect range.

However, this process does not provide a quantitative measure of inspection capability of the type that could be used for instance in the connection of the risk-informed in-service inspection (RI-ISI) process. In a quantitative RI-ISI, a quantitative measure of inspection effectiveness is needed in determining the risk reduction associated with inspection. The issue of linking the European qualification process and a quantitative measure of inspection capability has been discusses within the ENIQ over several years. In 2005 the ENIQ Task Group on Risk decided to initiate an activity to address this question. A program of work was proposed to investigate and demonstrate an approach to providing some objective measure of the confidence which comes from inspection qualification, and allowing risk reduction associated with a qualified inspection to be calculated. The work plan focuses on following issues:

- Investigating sensitivity of risk reduction to POD level and detail;
- Investigating the use of user-defined POD curve as target for qualification;
- Testing a Bayesian approach to quantifying output from qualification;
- Linking qualification outcome, risk reduction and inspection interval;
- Pilot study of overall process, including a pilot qualification board.

The work was organised in a project called “Link Between Risk-Informed In-Service Inspection and Inspection Qualification”. The project was partly funded by a group of nuclear utilities. The project is presented in detail in a separate paper in these proceedings [11].

INSPECTION QUALIFICATION BODIES COOPERATION

Both in Europe and internationally there is now a wide implementation and in several countries long experience with Inspection Qualification. At several meetings and in reports over the last year’s qualification body, members have asked for better ways to exchange experiences and cooperate. Ideas
to form a “Qualification Bodies network” have also been aired. Thus, JRC took the initiative to a 1st International Workshop for ISI Qualification Bodies, which was organised in cooperation with IAEA in Petten, NL, November 2006. The objectives for the meeting were for QBs to exchange information and experience and to identify areas for cooperation. In total 33 persons from 18 countries around the world participated: ARM, BE, BU, CAN, PRC, CZ, FIN, FR, HU, RO, RU, SL, ES, SE, CH, UKR, US, IAEA, EC. In this first meeting it was shown that most countries have developed a qualification system and that the most widely applied methodology is ENIQ (in combination with IAEA in some countries) \[12\]. The workshop concluded with:

- a list of issues that arose from the workshop for future consideration,
- several recommendations/actions, and
- a strong desire to continue with the series of workshops.

The most important issues arising from the meeting were:

- Test piece fabrication
- Derivation of inspection objectives/technical specification
- IQ/PD in relation to plant life management
- Qualification levels/tiers
- Exchange of qualifications between countries
- Personnel qualification
- Relationship between IQ/PD and RI-ISI
- Improved harmonisation of qualification approaches

In the meantime, two more workshops were held, which were both jointly organized by IAEA and JRC.

CONCLUSIONS

In-service inspection continues to be an important issue, and attracts a lot of attention, shown by this conference and several reported activities in Europe.

Within the European Network for Inspection and Qualification – ENIQ – utilities, vendors, R&D etc continues to develop harmonised approaches for Inspection Qualification and for Risk-informed ISI. Inspection Qualification has been introduced broadly in Europe and the experience is used to continuously update the ENIQ Methodology and Recommended Practices. The widespread use of the ENIQ documents have been confirmed by an official survey on Nuclear Safety, performed under the European Council, and its usefulness has been confirmed by WENRA – Western Nuclear Regulators Association.

Specifically, a novel approach on how to perform ENIQ qualifications resulting in quantitative results, through a Bayesian approach, has been developed and tested, in a project that aims at developing the link between NDT qualification and RI-ISI.

As inspection qualification bodies have been established in Europe and internationally, they have started a formal cooperation through a series of international workshops.

Additional information concerning ENIQ and its task groups and activities, as well as publications, can be obtained from the ENIQ website: [http://safelife.jrc.ec.europa.eu/eniq](http://safelife.jrc.ec.europa.eu/eniq).

REFERENCES


