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GUIDELINES FOR THE DESIGN OF TEST PIECES AND CONDUCT OF TEST PIECE TRIALS

ISSUE 2

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GUIDELINES FOR THE DESIGN OF TEST PIECES AND CONDUCT OF TEST PIECE TRIALS

ISSUE 2

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Approved by the ENIQ Steering Committee

ENIQ, the European Network for Inspection and Qualification, publishes three types of documents:

Type 1 — **Consensus documents**
Consensus documents contain harmonised principles, methods, approaches and procedures and emphasize the degree of harmonisation between ENIQ members.

Type 2 — **Position/Discussion documents**
Position/discussion documents contain compilations of ideas, express opinions, review practices, draw conclusions and make recommendations for technical projects.

Type 3 — **Technical reports**
Technical reports contain results of investigations, compilations of data, reviews and procedures without expressing any specific opinion or evaluation on behalf of ENIQ.

This ‘ENIQ Recommended Practice 5: Guidelines for the Design of Test Pieces and Conduct of Test Piece Trials (ISSUE 2)’ (ENIQ Report No 42) is a type 1 document.

FOREWORD

The present work is the outcome of the activities of the ENIQ Task Group Qualification (TGQ).

ENIQ, the European Network for Inspection and Qualification, is driven by the nuclear utilities in the European Union and Switzerland and managed by the European Commission's Joint Research Centre (JRC). It is active in the field of in-service inspection (ISI) of nuclear power plants by non-destructive testing (NDT), and works mainly in the areas of qualification of NDT systems and risk-informed in-service inspection (RI-ISI). This technical work is performed in two task groups: TG Qualification and TG Risk.

A key achievement of ENIQ has been the issuing of a European Methodology Document, 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 flaw detection and sizing capability. A qualification body reviews the TJ and the results of any test piece trials, and issues the qualification certificates.

The purpose of this ENIQ Recommended Practice 5 (Issue 2) is to identify issues to be considered when designing test-pieces for use in experimental inspection qualification trials and provides recommendations for conducting these trials. This document is intended to help plant owners, inspection qualification bodies, inspection designers and inspection vendors in the execution of their respective roles in the qualification process. It is also intended to help the user in understanding the influence of essential input for the design of test-pieces.

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1 SCOPE

This document identifies issues to be considered when designing test-pieces for use in experimental inspection qualification trials and provides recommendations for conducting these trials. The document will help plant owners, inspection qualification bodies (IQBs), inspection designers and inspection vendors in the execution of their respective roles in the qualification process. The document will also help in understanding the influence of essential input for the design of test-pieces. Examples of essential input are:

- List of defect influential and essential parameters
- Inspection requirements
- Sizing tolerances, etc.

The ENIQ Methodology is a framework that combines technical justification and results from practical trials to provide evidence that the inspection system is capable of meeting the inspection objectives. The technical justification and the practical trials are intimately linked in that:

- The technical justification identifies the essential parameters for the inspection, thereby recording those parameters that have a bearing on the inspection performance.
- The technical justification presents those aspects of the inspection that are most complex.
- The technical justification performs physical reasoning and other analyses to identify the worst case defects (those defects that are most challenging for the inspection). This process plays an important role in reducing the number of test-pieces.
- The technical justification can make proposals for the design of test-pieces.

This document is relevant to any inspection situation, but most illustrations are centred on ultrasonic and eddy-current inspection of steel components.

The ENIQ approach has been deliberately developed to allow the role and design of test-pieces and practical trials to be optimised for each specific case. This document discusses how this “case-based” approach can be applied to the design of test-pieces and practical trials. Additionally this Recommended Practice discusses the application of quality management to the test-piece fabrication process, which should be considered along with the quality requirements of the entire qualification process.

Requirement for practical trials

The ENIQ methodology can be used to qualify both inspection procedures and inspection personnel (where required). Generally these are performed separately.

The aim of procedure qualification is to gather and assess evidence to demonstrate that the inspection system and the instructions contained in the inspection procedure are capable of meeting the inspection objectives.

Personnel qualification, where required, is normally performed following a satisfactory procedure qualification. This phased approach tests the ability of the key inspection personnel to perform roles necessary for the inspection to deliver its objectives. The task for which personnel qualification is most often used is data analysis and interpretation. In some areas it is common practice to make a further division between the tasks of defect detection and defect sizing (and characterization if required).

Practical trials of the inspection system play an important role in both procedure and personnel qualification and are most commonly used to:

- Provide experimental evidence for the inspection capability to be included in the technical justification
- Demonstrate the statements in the technical justification about the performance of the procedure
- Demonstrate the statements in the technical justification about the performance of the equipment and manipulator
- Qualify inspection personnel.

2 Design of Practical Trials

Before designing the practical trials, it is assumed that all of the input information is available including:

- component geometry
- component materials
- manufacturing processes (welding procedures, forging specifications)
- defect details
- inspection objectives
- environmental variables (temperature, hygrometry, radiation level, fluid level in the circuit)

2.1 General Issues to consider in designing trials

The fabrication of test pieces is often time-consuming and sometimes costly. Where test pieces are required it is recommended that full use is made of the technical justification to minimise the number of test pieces.

The balance between test-piece trials and technical justification will vary greatly depending upon the inspection situation being qualified. Important considerations are:

- the complexity of the inspection situation
- the degree to which theoretical modelling can be used to predict inspection performance
- the availability of prior experimental data and inspection experience
- any previous qualifications
- the qualification level.

The extent of experimental demonstration necessary and the design of the trials is ultimately dependent on the IQB's judgement based on the amount of necessary evidence in the technical justification[1] and the complexity of the inspection, and in most cases will be based upon the above factors. It is expected, however, that the IQB will respond to any proposals made in the technical justification and the availability of existing test pieces.

The ideal qualification test-piece would be fully representative of the plant component. It would contain a set of defect conditions which themselves are fully representative of those sought by the inspection and whose parameters were known to high precision. In many situations it is not practical to achieve this ideal and a balanced case-based choice of specimen geometry, material composition and defects must be made.

It is important to maximise the cost effectiveness of test pieces by considering the objective of the practical trials, some examples being:

- Practical trials may be needed to confirm that the inspection techniques are capable of detecting and/or sizing complex defects. Here it may be necessary to concentrate on fabricating a large number of representative defects (for example to generate some statistical information) in small components of simple geometry.
- The trials may focus on different parts of the inspection, such as procedure, NDT system, personnel etc.
- Test pieces representing the full geometry of the component may be needed to test the application of a manipulator to a complex component and to demonstrate the coverage over the inspection volume.
- The type of defect response required: Realistic or Target. Depending on the goal of the qualification, either may be suitable. Realistic defects are those that provide a signal response corresponding to that expected from a genuine defect. Target defects are artificial defects such as EDM notches.

2.2 Generic types of practical trials

The previous section discussed the need to maximise the effectiveness of practical trials. This section discusses some of the different types of trials that can be conducted. In all cases the scope of the practical trials is something that should be agreed upon by the plant owner, inspection vendor and IQB.

2.2.1 Holistic or Full-System Demonstration

One of the most rigorous approaches to practical trials that can lead to the highest level of confidence in the inspection performance is to use practical trials that demonstrate the full system. This is where the qualification exercise is performed using test-pieces which closely resemble the component to be inspected and contain intentional defects with a signal response for the NDT system that is representative of those sought in practice. Such trials typically require use of the full inspection system that is to be deployed on site.

[1] Occasionally, conditions may be imposed by the plant owner or regulator regarding the minimum number of defects to be included in the exercise.

Whilst the application of the full inspection system gives the opportunity to assess the overall capability of the inspection, it has some disadvantages:

- It can be very difficult (and in many cases not practically possible) to manufacture controlled, representative defects, particularly in large and complex geometries.
- Large test-pieces can be difficult and time-consuming to make and hence expensive. Often the high cost of test-pieces restricts the number that can be manufactured and consequently (for blind trials) it can be difficult to preserve the confidential nature of the defect distributions.
- Some fully representative test pieces can be very large and require large storage and handling facilities.

However if a non-volumetric method is used (e.g. eddy current, visual or penetrant), it is probably not necessary to make test-pieces with a volume larger then the method requires.

A variation to this approach is to simulate the full geometry of the inspection situation by using models manufactured as a mock-up (e.g. in wood, plastic or thin sheet steel) into which test-pieces representing a relatively small section of the component can be inserted. This approach can have several advantages:

- Several smaller test pieces can be inserted into the mock-up, thereby easing the problem relating to confidentiality.
- The overall cost and the handling issues can be reduced significantly.
- Further smaller section test-pieces can be fabricated at later dates to allow for a change in the inspection requirements or inspection techniques (for example if ultrasonic inspection is changed to eddy-current). This could also be done if the confidentiality of the existing inserts was felt to be compromised (for blind trials).

For blind trials, test-piece security (control of access to information on defect location, character and dimensions) needs to be maintained or the significant investment associated with the test-piece or test-pieces can be lost and/or the validity of the output may be degraded.

2.2.2 Parametric studies

Parametric studies are often used to provide information for the technical justification but can equally be applied by the IQB as part of either open or blind trial activities. Parametric studies might be part of the holistic demonstration, although this can further add to the time and cost of the qualification process.

An alternative to holistic demonstration is to use test-pieces which replicate only part of the inspection situation. For example, a weld in a thin plate might be an adequate representative of a Reactor Pressure Vessel weld for surface inspection techniques or to assess the capabilities of the mechanical system. The advantages of using this approach are many, although it must be recognized that such test-pieces can only be used to assess the capability of a part of the inspection system. The technical justification should explain this.

The design of parametric study specimens and the assurance that they replicate the inspection situation sufficiently in the vicinity of the defect is an area in which inspection modelling might be applied to give greater confidence.

3 Test-piece Design

One of the strengths of the ENIQ methodology is its flexibility. However this flexibility means that there is little prescription which can direct activities such as the design or use of test-pieces. This document aims to identify issues of importance which may need to be considered when making critical decisions in the design and use of test-pieces.

The extent to which experimental demonstration is required should be defined by the qualification procedure, which must provide sufficient information to allow test-piece requirements to be specified. In some cases the extent of pre-existing evidence will only become apparent as the TJ is being written, then the qualification procedure should be updated to reflect this.

Test-piece requirements may also be influenced by existing information:

- Valid previous evidence of capability can justify a reduction in the experimental demonstration requirement.
- Existing test-pieces may be used to provide the necessary capability assessment.
- Pre-recorded data from similar applications can supplement or negate the need for a new experimental programme.

In many cases, especially first-of-a-kind qualification, the IQB is likely to require new test-pieces to execute the qualification procedure. This will require some design process to be followed to decide upon the geometry of the test-piece(s) and upon the defect parameters such as type, location etc.

The extent of the demonstration is determined by the IQB who will weigh issues such as the extent of any existing evidence and qualifications, the safety consequences of the inspection, and the novelty and complexity of the inspection. Even when the inspection is simple, a number of defects will be used in the test-pieces since multiple results are needed to establish inspection capability and reliability trends. In complex cases where there may be many different defect definitions, capability demonstration for one element of the potential defect population does not imply performance for other elements of the potential defect population, which place different, possibly more demanding requirements upon the inspection. For test-pieces to supply the required assessment and assurance in these complex cases, there must be a large enough population of defects to test capability throughout the range of defect possibilities contained in the inspection scope. These variations and requirements and the number of defects shall be decided upon for each qualification by the plant owner, vendor and IQB.

3.1 Use of Worst-Case Defect assessment

For worst-case defects to be used in test pieces, it is first important to establish what defects are to be implanted and where. The IQB normally holds a meeting with the technique developer in advance of the TJ being issued. This allows the developer to outline his likely technique approach and thus give the IQB an idea as to areas of possible difficulty. This interactive approach also gives the developer an idea as to where defects should be placed in his own development test samples. It is important that both parties have a common understanding of worst-case defect scenarios such that the optimum technique is developed and optimum qualification performed.

The defect description generally includes a range of different parameters such as:

- Location (circumferential, through-wall and longitudinal)
- Orientation (tilt and skew)
- Roughness
- Size

To simulate all combinations of these parameters within a realistic number of test pieces is often not practical. Consequently the concept of worst-case defects is used. Here, those combinations of parameters that pose the greatest challenge to the inspection are identified and then included in the test-pieces.

The rationale of using worst case defect assessment can be explained as follows. If capability can be demonstrated for this most challenging set, then it follows that capability can be inferred for the rest of the defect set specified in the inspection scope.

This rationale may also be used to assess the capability of similar inspections applied to a group of similar components and from this assessment, to identify the worst case component, thus reducing the number of test-pieces from one per component type in a group to one or two to describe the entire group.

There are however, some potential problems with worst-case analysis which need to be understood if it is to be used successfully:

- There must be high confidence in the worst-case analysis performed, as it strongly influences the test-piece design and hence the outcome of the demonstrations.
- The worst-case population may vary with changes in inspection parameters or with the NDT method considered (for instance UT in lieu of RT). So if the inspection parameters change, so may the worst-case defects. This means that if test specimens are designed and built before the inspection parameters are fully determined, there is a risk that the test-piece defect population may not represent a valid worst case set for the inspection when it is finally qualified.

The inspection scope may include broad parameter ranges. All permutations of parameter may be neither equally likely nor give rise to the highest safety consequence defects. For this reason it is normal to include defects which are representative of the most likely and most safety significant classes in test-pieces, as well as those which are most difficult to detect or characterise.

Worst-case design schemes can be used to define defect populations for both open and blind test-pieces. When used it is important that candidate vendors do not optimise their inspections on the open-trial test-pieces because such adjustment of inspection parameters may strengthen capability for the original worst-case population at the expense of other portions of the inspection scope range. Hence it is advisable that specimens include examples of most of the defects included in the technical specification for the up-coming inspection, in addition to the “worst-case” defects.

It is not recommended to use only worst-case defects in a qualification. A combination of worst-case and more likely defects is preferred.

3.2 Number of Defects in Test Pieces

The types and numbers of defects in test pieces shall be decided between the parties, based on the type and complexity of the inspection situation.

The number of defects also depends on the owner plant‘s requirements and the vendor’s choice of physical phenomena. For instance for UT Techniques:

- Corner effect
- Tip diffraction
- Mirror effect
- Mask effect.

With the objectives to fit purpose (detection, sizing and characterization)

It is often tempting to maximise the number of defects in each specimen to minimise the cost per defect. Experience has proved this mindset to lead to many technical problems in demonstrations for defect detection. This is because the volume of defects is high and unrealistic. The defect conditions in the test piece do not challenge the inspection system’s capability to perform properly in a practical situation. Sparse defect populations with defects irregularly distributed will provide a more challenging and realistic inspection situation for assessment.

This guidance is relatively easy to apply if the range of defect parameters is small and the concept of worst-case defect assessment is applied. In this case the assessment of the practical trials, combined with the assessment of the technical justification, will lead to a qualitative judgement on the performance of the inspections. On the other hand, if statistical information is required from the test piece trials then the number of defects will need to be considerably larger.

4 Test-piece Fabrication

4.1 Quality Management for Test-piece Fabrication

It is vital that appropriate quality controls are applied during the specification, fabrication and use of test specimens. These quality controls, as a minimum, should be applied to:

- test-piece geometry
- suitability of test-piece materials
- material condition including heat treatment history
- welding processes
- surface form and finish and cladding
- defect specification (see section 3)
- requirements for test-piece fabricator's confirmatory inspections
- retention of test-piece fabricator's records
- tolerable unintended defects
- acceptable repair processes
- documentation of the fabrication process
- receipt inspections to confirm the acceptability of the as-built test-pieces including the structural form of the test-pieces, presence of unintended defects, acceptability of stipulated defects, material properties, etc.
- supplementary confirmatory inspections (see section 4.4)
- test-piece security during fabrication, storage and use.

The extent of this material and the identification of essential parameters need to be decided.

4.2 Fabrication Specification

As part of the quality management system, a documented fabrication specification should be provided which specifies all requirements for the fabrication process including those listed above in section 4.1. The fabrication specification should be agreed in advance with the test-piece fabricator. It is recommended the fabrication specification includes an activity list which identifies critical activities in the fabrication plan that can be independently witnessed or verified to complete the control of the fabrication process. The significance of any departures from design intent should be assessed against the design intent and either formally accepted or rejected. In the latter case, remedial action will be required.

4.3 Test-piece Defect Tolerance

The inspection scope will generally require the inspection to measure certain defect parameters to better than certain tolerances. Parameters which are commonly required to be measured are:

- Location
- Size
- Ligament

If the means of assessing the inspection's capability to deliver measurements of these parameters is to be established exclusively from the experimental demonstration on test-pieces containing defects, it is essential that the true values of these sought parameters for the test-piece defects are known more accurately than the tolerance

requirements given in the inspection scope. This may not be easily achieved, especially in the case of ‘difficult’ inspections. The IQB must give attention to finding ways of measuring the defect parameters that are better than those that will be tested in the demonstration.

The test-piece fabrication specification should place tolerances on test-piece defect parameters. Test-piece vendors typically quote tolerances on test-piece defect parameter values. These values alone are often insufficient and it is recommended to consult with the IQB prior to fabrication to agree upon tolerances, especially when the accuracy claimed is at the limit of capability for the measurement techniques used. The extents of fabricated defects should be checked as far as possible.

If tight tolerances are put on flaw parameters, this can influence the overall choice of acceptable test-piece defect types. In general terms it is difficult to establish the parameter values of complex defects to high accuracy. In some cases it may be possible to do destructive examination to accurately size complex defects, at the expense of course of future use of the test piece. In other cases, in order to establish defect parameters to a tight tolerance, it is necessary to make use of simple test-piece defects such as electro discharge machined (EDM) slots. However, in making this choice, there is an element of compromise in the extent to which the inspection responses which will be encountered on the test pieces will match those which would be expected in plant.

4.4 Supplementary Inspections

In some cases it may be judged necessary to apply additional inspections beyond those which the test-piece fabricator performs to confirm compliance with the fabrication specification. These inspections can be applied as the defects are being introduced into the test piece and/or when the specimen fabrication is complete.

These supplementary inspections can be used for a number of purposes including:

- confirmation that the defects are typical of genuine defects in plant
- checking that there are no significant artefacts of the fabrication process
- generating an ’expert’ data set which can be compared to the known defect parameters and/or the data generated by candidate inspections applied during the qualification exercise or as a basis for pre-recorded datasets

In any event it can be seen that these supplementary inspections are of key importance and should be controlled using formal inspection procedures and adequate quality management (see section 4.1 above).

When selecting supplementary inspection methods consideration must be given as to how the information will be used. As an example, X-ray tomography can extend the information which can be obtained from supplementary inspection. However, to be able to compare real indications from implanted defects is it recommended to use the same inspection technique as the vendor will use during the inspection so the same inspection parameter such as technique, inspection access sensitivity and other parameters that can be inspection specific.

The combination of analysis of supplementary inspections coupled with the fabrication record of as-built defect parameters can be used to produce a best estimate of critical flaw parameters, referred to here as 'the definite defect dimension record'.

Another possibility is that some portion of the fabricated defect set could be destructively examined to determine or confirm generic parameters. This option is particularly attractive when the data from specimens are to be used in trials using pre-recorded inspection data (see above).

5 References

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