EUROPEAN COMMISSION
DG-JRC – Institute for Advanced Materials
Joint Research Centre

DESCRIPTION OF THE INPUT DATA FOR THE ENIQ PILOT STUDY

November 1998 ENIQ Report nr. 7 EUR 18116 EN

Approved by the Steering Committee of ENIQ

Directorate-General
Joint Research Centre

Published by the
EUROPEAN COMMISSION

Directorate-General
Telecommunications, Information, Industries and Innovation

L-2920 LUXEMBOURG

LEGAL NOTICE

Catalogue number: CD-NA-18116-EN-C

Printed in the Netherlands

APPROVAL SHEET PILOT STUDY DOCUMENT

TITLE DOCUMENT: **Description of the situation for the ENIQ pilot study**

DOCUMENT NUMBER: **ENIQ.PILOT(96)3**

This document was distributed for final comments on 23/10/96:

signature of programme manager:

This document was approved following the written procedure on 29/11/96:

signature of programme manager:

Final version of this document has been issued on: 28/09/98

signature of programme manager:

CONTENTS

1. SCOPE

In the second version of the European methodology, it is clearly stated that, prior to the start of the inspection qualification, it is very important that the parties involved agree on the exact situation to be considered. Under situation is understood in this document all information related to the component, the type and size of defects to be considered, objectives of the inspection qualification and the inspection performance (detection, sizing and location) to be achieved. The inspection procedure is, in principle, also part of the situation. The exact situation to be considered for inspection qualification is a matter to be agreed between the involved parties. The determination of the safety relevance of components or defects is part of the definition of the situation. Definition of critical defect sizes and/or safety margins and structural integrity reasoning are also part of the definition of the situation.

In this document, the situation considered in the ENIQ pilot study is described.

2. DEFINITIONS

For the purposes of Task 2.2, the definition of terms given in the "Glossary of Terms and Standards Used in Qualification" – draft final report of 24 October 1995 – will apply. This draft final report funded by the CEC DGXI under Contract Number ETNU/CT/94/0132-UK has been widely circulated within ENIQ.

3. GENERAL DESCRIPTION OF THE TASK 2.2 PILOT STUDY

As mentioned under Scope above, the pilot study will be carried out in accordance with the principles set out in the European Methodology Document. It aims to explore the way in which detailed procedures for qualification of inspection are developed from these principles. In doing this, the intention is also to provide evidence that qualification carried out in this way is satisfactory in terms of providing confidence that the inspection is capable of meeting the requirements imposed on it by an overall structural integrity safety case. The way this will be achieved is by applying the general principles of the European methodology to one specific example.

For the purpose of the pilot study, the qualification of an inspection of austenitic pipe to pipe and pipe to elbow welds was chosen as an example. All aspects of the inspection will be qualified. The procedure and equipment qualification will involve open trials on test pieces containing defects, while that of the personnel will be done through blind trials. In addition to practical trials, qualification will also involve the production of a technical justification as required by the methodology document.

The inspection, which will be qualified, will be an automated one involving a scanner and digital flaw detector. The inspection procedure will be produced specially for this exercise and will be tailored to the particular requirements of this inspection.

Qualification will involve a combination of satisfactory practical trial results and a convincing technical justification. If qualification reveals shortcomings in any aspect of the inspection, modifications will be made and the qualification *must* be repeated.

Once the inspection system has been qualified, it will be applied to a number of “real” components, some containing defects removed from operating reactors and others containing simulated defects but welded using the same materials and procedure as the qualification test pieces. The results obtained will be compared in detail to those in the qualification part of the pilot study. From this comparison, conclusions will be drawn about the value of qualification methodology in providing confidence in the inspection. As indicated above, two types of ISI components under test will be considered:

1. a first set for which the qualification test pieces replicate exactly the size, geometry and macrostructure;
2. a second set on which less information is available and for which the qualification test pieces doe not replicate in detail the size, geometry and macrostructure.

It will be interesting to compare the results obtained on these 2 different sets of ISI assemblies although it should be stressed that the first set is considered to be the most important one.

4. DESCRIPTION OF THE COMPONENT TO BE NON-DESTRUCTIVELY TESTED

The components to be inspected are austenitic pipe to pipe and pipe to elbow welds. The parent materials are wrought 304/316 austenitic steel and the welds are GTAW/SMAW. The inner surfaces of the assemblies are counterbored adjacent to the welds and the weld roots are undressed. The weld crowns are ground (not of second set of ISI assemblies). Access is limited to the outside surfaces.

Details of the geometry of the qualification specimens are summarised below:

- Diameter Range: 320 - 406 mm
- Thickness Range: 13.5 - 28 mm
- Weld Method: manual GTAW and SMAW
- Weld Material: E308 and E316

Details of the 2 sets of ISI assemblies are summarised below:
1st set of ISI assemblies:

- Diameter Range: 320 - 406 mm
- Thickness Range: 25 - 28 mm
- Weld Method: manual GTAW and SMAW
- Weld Material: E308 and E316
- Weld crown: ground
- Weld root: as welded

The qualification test pieces are very similar to this 1st set of ISI test pieces.

2nd set of ISI assemblies:

- Diameter Range: 320 - 710 mm
- Thickness Range: 16 - 30 mm
- Base Material: unknown, possibly E304
- Weld Method: unknown, possibly MMA
- Weld Material: unknown
- Weld crown: as welded (possibility to grind unlikely)
- Weld root: as welded

As already mentioned before, the qualification test pieces doe not replicate in detail the size, geometry and macrostructure found in the 2nd set of ISI assemblies.

5. DESCRIPTION OF TYPE AND DIMENSION OF DEFECTS TO BE DETECTED AND SIZED

The defects, which have been postulated as inspection objectives for the pilot study, are as follows:

- IGSCC in the parent material adjacent to the welds. These defects originate at the inner surface of the pipes and are parallel to the weld with a maximum skew of ±10°. Mean angle of tilt is 0°, but because of the irregular and branched nature of IGSCC, can vary by ±10°.
- Thermal fatigue cracks in the weld metal. These may originate at the weld surfaces or at pre-existing manufacturing defects within the body of the weld. Such defects are parallel to the weld with a maximum skew of ±10°. Angles of tilt can vary between 0° and the fusion face angles up to 30°.

6. SAFETY OBJECTIVE

Defects which exceed 50% of the wall thickness are critical from a structural integrity standpoint.

7. INSPECTION PERFORMANCE TO BE ACHIEVED (ISI OBJECTIVES)

To ensure that no defects of this size will escape detection *and* correct sentencing, the required performance levels are as follows (see Section 8 for logic behind it):

For pipe thickness < 20 mm
- Defects exceeding 25% T are unacceptable and 100% detection is required
- For defects between 3 mm and 25% T, the detection rate required is 80%
- The maximum undersizing permitted is 25% T.

For pipe thickness > 20 mm
- Defects exceeding (50% T - 5 mm) are unacceptable and 100% detection is required
- For defects between the above size and 3 mm, the detection rate required is 80%
- The maximum undersizing permitted is 5 mm.

For all thicknesses
- Defects smaller than 3 mm are acceptable
- RMS depth sizing error should not exceed 3 mm
- RMS length sizing error should not exceed 20 mm
- For defects sized above that at which 100% detection is required, there should be no false calls
- For defects which are sized below that at which 100% detection is required, false calls should not exceed 1 per 2 metres inspected weld
- Accuracy in depth location should be such that the error in measuring the ligament to the nearest surface is less than 3 mm
- Accuracy in circumferential location should be such that the maximum lack of overlap between the actual and reported defects should not exceed 10 mm
- The aspect ratio of the defects should not be smaller than 1 to 1.

8. LOGIC BEHIND CHOICE OF PERFORMANCE LEVELS

In this chapter, the logic behind the choice of performance targets chosen by ENIQ is described. The defects themselves were selected on the basis of experience of the defect types which may occur in components similar to the ones which form the subject of the pilot study. Their positions, roughness and orientations are derived from a knowledge of the growth mechanism and the nature of the defects which it can produce. In the past, the performance required in practical trials has often been derived in an arbitrary way with little associated logic. In the ENIQ pilot study, an attempt has been made to provide a logical foundation to the choice of performance requirements.

8.1 Detection and through-wall size measurement

8.1.1 Permitted undersizing and 100% detection levels

As stated above, the objective of qualification is to ensure that an inspection has the necessary capability and that it is highly likely in practice to detect *and* correctly sentence all defects exceeding a certain size. This size is usually based on fracture mechanics calculations and crack growth rates. A safety factor is then often applied to the calculated figure and the resulting size is referred to as the qualification size. In the case of the pilot study, a figure of 50% of the wall thickness has been arbitrarily assumed as the qualification size. For qualification of real plant items, this size will be calculated as discussed above and will be one of the inputs to the qualification process. The pilot study, on the other hand, is intended to illustrate the process of qualification according to the ENIQ principles and so the precise method used to produce the qualification size is not important.

Because of its significance for plant integrity, it is essential that defects with true sizes equal to or exceeding the qualification size a_{qual} are detected and sentenced with 100 % certainty in the practical trials. This requirement will be met provided:

a. all defect with a *true* size exceeding a_{qual} are detected in the practical trials
b. all defects with a *measured* size exceeding (a_{qual} - ?a_{max}) are sentenced as rejectable (in the trials and the actual inspection), where ?a_{max} is the maximum possible undersizing error.

The second criterion ensures correct rejection of defects with a true size exceeding a_{qual}, even if they are undersized by the maximum possible amount.

Criterion (a) has a drawback as it stands. It would allow a successful qualification, even if a defect with a true size only slightly below a_{qual} went undetected. This is clearly undesirable: there should be some margin between the qualification size a_{qual} (the size at which all defects must be detected and rejected in the actual inspection) and the size a_{100} for which 100 % detection is required in the qualification. The size of this margin a_{qual} - a_{100} can be arrived at using judgement or possibly by appealing to fracture mechanics specialists. In this pilot study, we simply take the margin to be equal to the maximum undersizing error ?a_{max}, which is always at least 3 mm. Thus, the 100 % detection size a_{100} for the qualification is given by:

$$a_{100} = a_{qual} - ?a_{max}$$

The precise values adopted for the maximum permissible undersizing and the size at which 100% detection is required, are a matter for judgement. If either is set too small, it may be impossible for the inspection to meet the requirement and hence be qualified. A balance must be struck so that the above requirement is met and also that the values adopted are judged to be achievable. This is the process that was followed in setting the values in Section 2 above.

For wall thicknesses between 12 and 20mm, it was judged impracticable to set Δa_{max} and a_{100} at values lower than 25%T, because this produces figures varying between 3 and 5 mm. Three mm is judged to be at the limit of what ultrasonics is capable of in these materials for both parameters.

For thicknesses in excess of 20mm it was felt unnecessary to relate Δa_{max} to wall thickness because this would have produced unnecessarily large values for the thicker samples. Instead, Δa_{max} was set at a fixed value of 5 mm and so a_{100} becomes (50% T - 5) mm.

In the above discussion, Δa_{max}, refers to the largest error recorded in the practical trials. It is recognised that, because errors fall on a distribution curve, there is a high probability that larger errors than those recorded in practical trials on a limited number of samples will occur in practice. However, as discussed above, the limit of capability for size measurement accuracy by ultrasonics is about 3mm and tighter values than those adopted would simply lead to automatic failure. The limitation in the degree of confidence in inspection that qualification can provide under the present circumstance must therefore be recognised. The situation improves for the thicker samples but, even for these, the situation is not as good as it would be for ferritic components. This is because it is not possible to decrease a_{100} to the same extent as in ferritics in order to reduce the demand on sizing accuracy.

The discussion above is based on a qualification defect size of 50% T. If this were larger, it would allow larger values to be adopted for a_{100} and Δa_{max}. The maximum undersizing observed in practical trials could also be set at some fraction of the maximum permissible undersizing to allow for the distribution of errors. These measures would improve the confidence in the inspection resulting from qualification. This emphasises the necessity for the qualification size to be as accurate as possible and for pessimisms in the calculations and safety factors to be reduced to the maximum possible extent.

8.1.2 Detection requirements for smaller defects

Following from the discussion above, there is no need from a structural integrity standpoint to detect defects smaller than a_{100} with 100% certainty. Indeed, for defects as small as 3mm, this would be totally unrealistic. Ideally, the detection requirement should reduce progressively as size decreases, starting with 100% at a_{100} and diminishing to zero at about 3mm. In practice, the number of defects it is practicable to insert into test pieces is too small to allow such an approach. Consequently, defects in the size range from a_{100} to 3 mm have been grouped together and an overall requirement that 80% of such defects should be detected in practical trials has been set. This is judged to be a reasonable requirement which should be met by a good inspection. It ensures that the detection capability of the inspection does not drop off too rapidly at sizes below a_{100}.

Defects below 3 mm in through-wall extent are acceptable because this size is below that at which there is a structural integrity issue for all wall thicknesses. In addition, a requirement to detect and size defects below 3 mm with any degree of confidence is judged to be beyond the intrinsic capabilities of ultrasonics and would lead to automatic failure.

8.1.3 Oversizing in depth

From a structural integrity standpoint, the crucial requirement on through-wall size measurement is to ensure that undersizing, which would allow critical defects to be accepted, does not occur as discussed above. Oversizing carries an economic penalty in that acceptable defects can be rejected and lead to unnecessary remedial measures such as repairs or replacements. It does not have safety implications. Nevertheless, a well-designed inspection should not lead to significant oversizing and some control on this parameter is necessary. This has been done here by imposing a requirement on the overall RMS through-wall sizing error. The value adopted is 3 mm because this is judged to be achievable by a good inspection. It is also the value currently adopted for comparable qualifications in Appendix VIII of ASME XI.

8.2 Length measurement

Length is a parameter which has only a second order influence on structural integrity. Consequently, the need for high accuracy in length measurement is not so acute as for through-wall sizing. This is reflected in the simpler methods adopted in most inspections for length measurement. An overall RMS length sizing error requirement of 20 mm was judged appropriate to exercise the necessary control without imposing demands which would be impossible to meet.

8.3 False calls

False calls in which defects are reported where none actually exist have a consequence which is principally economic in practice. They can lead to unnecessary remedial action such as repairs or replacements but have no direct safety implications. In qualification practical trials, however, it is necessary to impose strict limits on the number of false calls allowed. This is because, at the extreme, it would be possible to achieve 100% detection of all significant defects by declaring every part of the component to be defective or by declaring all defect signals to arise from defects of through-wall extent equal to or exceeding a_{100}. To avoid this possibility, no false calls are allowed in practical trials in which defects exceeding a_{100} are erroneously reported where no defects exist.

For defects which are reported as below a_{100} in size, the requirements on false calls are different. In this situation, there is clearly no intention to increase the performance for unacceptable defects by reporting false calls. False calls of defects lower in size than a_{100} can arise from errors in misinterpreting grain structure noise or signals from geometrical features of the component. To check that the inspection is being carried out with care and that personnel interpreting signals have the necessary competence, a limit of 1 false call per 2 metres of inspected weld has been set. This level was obtained by the best teams that participated in the PISC III Action 4 capability study on wrought-to-wrought pipework welds.

8.4 Location accuracy

Location accuracy is important for two reasons. First, in a real inspection, the position of defects with respect to surfaces must be known with some precision because this affects their significance for structural integrity. For this reason, a maximum error in measuring the ligament between the defect and the nearest surface of 3 mm has been set. This represents the limit of what is possible ultrasonically and should be sufficient to establish defect significance.

The second reason why defect location is important, is to guide any repairs which might be necessary. Also, in qualification trials, defects must be reported with sufficient accuracy in their position that the correspondence of the reported defect with an intended one can be established. For this reason, there is a requirement that the maximum lack of overlap between the reported and actual defects is 10mm.

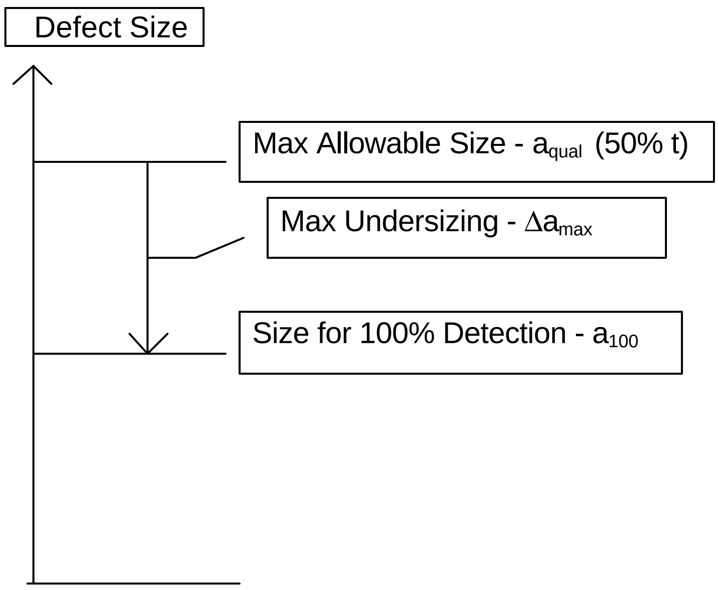

Figure 1: Relationship between defect detection and maximum undersizing

9. OBJECTIVES OF THE INSPECTION QUALIFICATION

The objective of the qualification to be carried out, is to provide confidence that the inspection is capable of meeting the requirements imposed on it by an overall structural integrity safety case. These requirements are described in detail in section 7 of this document.

10. INSPECTION PROCEDURE, EQUIPMENT AND PERSONNEL

The inspection procedure, equipment and personnel that will be used are described in the following documents:

- ENIQ.PILOT(95)1: Guidelines for the development of an inspection procedure
- ENIQ.PILOT(96)5: Inspection procedure for the ENIQ pilot study

EUROPEAN COMMISSION

EUR 18116 EN 11 pages

Editor: P. Lemaitre

Luxembourg: Office for Official Publications of the European Communities

1998 – 11 pag. – 21.0 x 29.7 cm

Physical sciences

EN

Catalogue number: CD-NA-18116-EN-C

Copies of this ENIQ report can be obtained by writing to the following address:
JRC Petten
Institute for Advanced Materials
P.O. Box 2
NL – 1755 ZG Petten
The Netherlands

ABSTRACT

One of the major achievements of the European Network for Inspection Qualification (ENIQ), composed of European nuclear plant operators, service vendors, qualification bodies and manufacturers, was the approval of the European methodology for qualification of non-destructive tests.

The first issue of this document was published in March 1995 and the second issue was published in February 1997. The ENIQ European methodology document describes inspection qualification as the sum of the following items: practical assessment (blind or non-blind) – conducted on simplified or representative test pieces resembling the component to be inspected and technical justification, which involves assembling all evidence on the effectiveness of the test, including previous experience of its application – experimental studies, mathematical modelling, physical reasoning (qualitative assessment) and so on.

In the European methodology, only general principles are provided on how to do inspection qualification. It does not contain detailed guidelines of how to do inspection qualification for a specific component. That is why, within the framework of ENIQ, it was decided to conduct a pilot study in order to explore ways of how to apply the European methodology allowing at the same time to test its feasibility for implementation.

In this document, the input information, which was used for the ENIQ pilot study on wrought stainless steel welds, is described.