

## Inspection Qualification II

### **Recent Advances in Artificial Cracks for NDT Development and Qualification**

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#### **ABSTRACT**

Defects are needed to develop new NDT methods and to assess the performance and reliability of used inspection methods and procedures. It is crucial to have representative defects in order to have an accurate and realistic assessment of the performance of NDT. Representativeness should be to the actual service-induced defects that the NDT method is used to evaluate. While various techniques have been used to create such defects, all conventional techniques seem to have some shortcomings that limit true assessment of the NDT performance. Currently, the used procedures and requirements do not promote efficient use of available defects. This paper describes use and selection of artificial defects for NDE qualification. Finally, real-world application cases are presented showing the use of such cracks.

#### **INTRODUCTION**

Inspection qualification is nowadays quite well established in the nuclear industry. While the requirements vary from country to country, most countries do require inspections to be qualified prior to actual inspection. The European Network for Inspection Qualification (ENIQ) has published a comprehensive set of recommended practices that cover most aspects of inspection qualification [1-10]. Most European countries follow the ENIQ methodology in inspection qualification to a varying degree. The methodology as well as the national requirements for inspection qualification have developed very rapidly in recent years.

One of the key issues in inspection qualification is the production of relevant test blocks to show the performance. Traditionally, there has been severe limitations in manufacturing test blocks with defects. In particular, the techniques available for producing representative defects to test blocks have had limitations. Also, the ENIQ methodology currently gives very limited guidance to this vital subject.

#### **Recent advances in artificial cracks**

In recent years new possibilities for producing real, natural cracks for qualification test blocks have emerged, tried and tested [11,12]. These techniques have developed and matured over the recent years and many of the traditional limitations of defect manufacturing have been overcome. The production methods to produce these grown cracks have been under significant scrutiny and they have now been validated and qualified for use in inspection qualification in various countries.

Due to the investigations done on grown cracks, there's now much new information on applicability of different artificial defects [13-15]. Also, various characteristics of both natural cracks [16] and artificial cracks have been studied and documented. Consequently, a sound body of technical information is now available for use in inspection qualification. However, this information is currently not used to its full potential. In fact, the ENIQ methodology does not currently facilitate selection of defects very well.

#### **ENIQ methodology**

The ENIQ methodology gives general guidelines for inspection qualification. Each European country has a set of authority requirements and current practices that define their implementation of the general ENIQ methodology. These implementations vary from country to country.

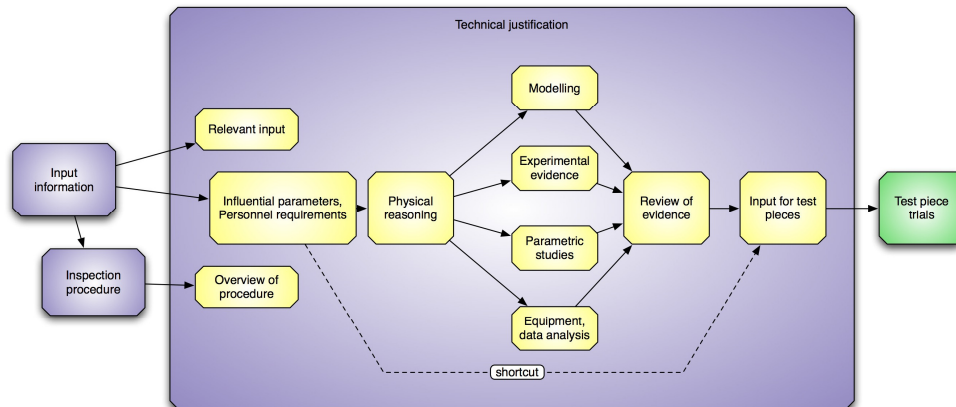


Figure 1 - General ENIQ flow chart [3]

The general ENIQ flow chart is shown in Figure 1. In general terms, the starting point of the qualification is the input information dossier. This contains information about the cracks that are expected in the component. The crack growth mechanisms as well as the critical flaw sizes are defined in the input information. The input information is typically prepared by the plant operator, who has best information on the possible damage mechanisms. Based on this input information, the inspection procedure is defined, usually by the inspection vendor.

When these two are available, a technical justification is prepared. It has been said, that the technical justification is the most important document in the qualification. This document takes the relevant data from input information and inspection procedure and defines the most important parameters for successful inspection. The applicability and performance of the chosen procedure is then justified using previous experimental evidence, modelling parametric studies etc. Finally, guidance is given for the test blocks to be used for open and blind trials in qualification.

With use of the technical justification, the test blocks can focus on testing the most important challenges of the inspection and the amount of needed test blocks and defects can be reduced. According to ENIQ, the amount of defects can be further reduced by using worst case -defects. In this case, the most difficult defects from inspection point of view are defined and tested for in the open and blind trials. It is then argued, that if the inspection method performs well even in the worst case defects, performance in other cases can be expected to be sufficient as well.

Clearly, the use of technical justification has some significant advantages. However, the process also has some problems related to test block manufacturing and defect selection. Information about cracks to be found is defined in the input information. However, as shown in the the flow chart (Figure 1.), the guidance to test block manufacturing comes only in the end of the technical justification. This leads to long information chain from the input information to the final defect specification. Consequently, the defect specifications tend to be dominated by inspection considerations and information relating to crack characteristics to be expected in real life is not preserved well. Also, the sequential process described in the flow chart can generate rather long timetables. In particular, the test block manufacturing takes time and it would be beneficial to be able to start it before the entire technical justification is finalized. ENIQ document also suggest this with the "shortcut" path. Furthermore, the worst-case specification may lead to unnatural defect specifications and tuning the inspection method with unlikely or impossible defect types. Finally, when the test blocks and defects are tightly coupled with the technical justification, they become specific to the qualification at hand. If the inspection method is developed in the future or if additional methods are needed to support the primary method, new test blocks are needed.

The ENIQ methodology covers most aspects of inspection qualification with great detail. The methodology document and the associated recommended practices cover 236 pages, in total. However, in all the ENIQ documentation, there's one paragraph (22 lines) that gives instructions on the manufacturing of defects. It's safe to say that defect manufacturing hasn't been emphasized in ENIQ

work so far. New version of this document is being prepared, which gives more guidance on how to select defects.

The ENIQ methodology mentions use of test blocks with defects in three phase: laboratory samples, open trials and blind tests. The purpose of the laboratory samples is to give background information and supporting evidence for the technical justification. These samples are also used to fine-tune the inspection procedure to maximize its performance.

The purpose of the open trials is to show, that the technique is able to achieve the performance defined in the technical justification. In open trials, the location and size of the defects are known and thus the NDE performance can readily be assessed by all involved parties.

Successful open trials alone are not considered sufficient to demonstrate real-life performance. It is necessary to demonstrate, that the NDE personnel can apply the technique/procedure correctly. Furthermore, most NDE techniques include human judgement, which may vary between inspectors and which may be influenced by the knowledge of the defect types in the open trials. The purpose of the blind trials is to demonstrate, that the personnel is able to correctly apply the technique and judge its results (even when the correct answer is unknown).

To fulfil this purpose, the defects in all test blocks should give representative response (in terms of essential parameters) as compared to the defects defined in the input information. The most obvious way to realize this is, of course, to use test blocks with natural grown defects. This has several advantages: the performance of the NDE system is shown with minimal uncertainties and inspectors get experience on true cracks and know what to expect. There's no room for discussions about the validity of the samples.

However, producing realistic flaws may not always be possible. So, the next option is to use semi-realistic crack simulations and then provide technical justification on how to address the shortcomings of the defects in the qualifications. This route has the advantage that the semi-realistic cracks are typically easier and less costly to manufacture. However, inferring real world performance becomes more difficult and the inspectors get less experience with true cracks. On the contrary, inspectors get experience, which is not natural and which may lead to unrealistic confidence on the inspectors skills or capability of the technique. Also, the technical justification makes the samples more case specific. Furthermore, there's a risk in re-doing the qualification if the justification later proves invalid.

Finally, even the use of clearly unrealistic notches can be justified for some cases. Here, of course, the justification becomes increasingly difficult as there's no direct information about the true performance of the inspection. Finally, if an indication is actually found, the test samples with notches provide no help to explain it and additional information is then required.

Figure 2. shows comparison of some of the often used defect types: grown cracks, welded crack simulations and EDM notches as well as true crack from the literature.

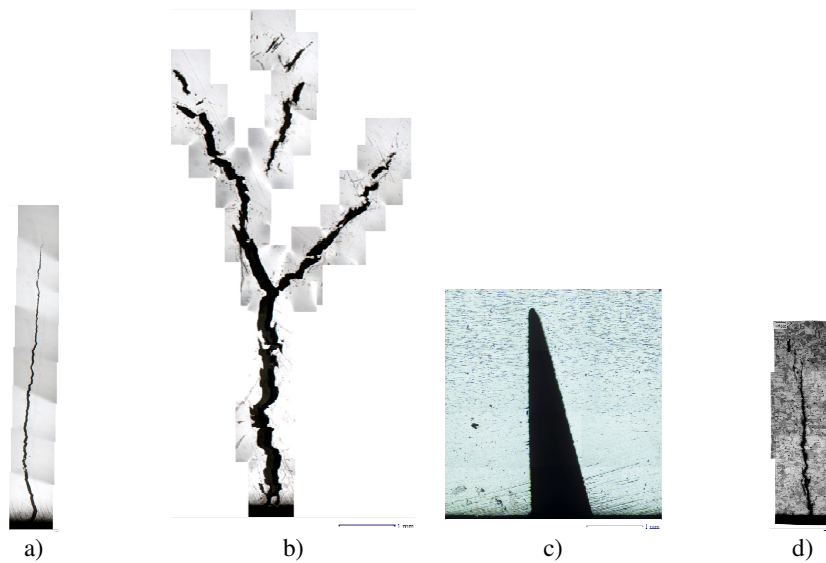


Figure 2 - Grown crack (a), welded crack simulation (b) and EDM notch (c) and true crack (d) from the literature [17]

Unfortunately, the ENIQ does not currently give clear guidelines on how to justify use of any of the available defect types or requirements for used defects. Consequently, these requirements and justifications need to be re-determined for each specific case with the experience available.

### Application of ENIQ

The ENIQ methodology provides general guidance to inspection qualification. However, each qualification body using it seems to have slightly different implementation of it. For example, the system used in Finland [18] follows roughly the following flow chart (Figure 3).

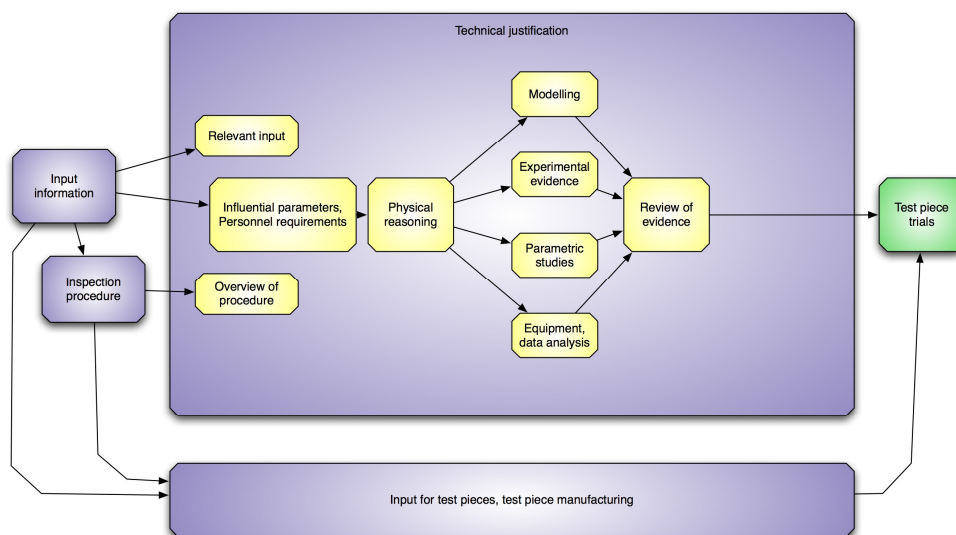


Figure 3 - Schematic flow chart of Finnish qualification

The main difference to ENIQ flow chart (Figure 1) is that the test blocks are defined based on input information and general features of the inspection procedure. The advantage of the described implementation is, that there's more direct link to the input information and the resulting test blocks are more generic. The test blocks can then often be applied for different qualifications and even totally different inspection methods. Also, the more parallel process improves the time needed.

The justification of the used flaws relies heavily on the experience of the involved parties. There's no clear set of requirements for flaws. Instead the applicability of defect types for each case are defined in discussion between the qualification body and the operator. When limited experience is available, defects may be rejected during fingerprinting, e.g., based on unrealistic response or unacceptable disturbances.

## **APPLICATION CASE EXAMPLES**

### **VTT research sample**

VTT is currently developing a monitoring system for online monitoring of material degradation in the primary circuit of a NPP. This may be needed, for example, if an indication is found in primary circuit during normal outage and the part can not be replaced or repaired during that outage, online monitoring system will be able to monitor the indication during the next operation period and confirm the safe operation of the NPP.

Currently, a pilot monitoring system is designed, constructed and tested as a part of a project called RAKEMON. RAKEMON is a project in a national research programme on nuclear power plant safety 2007 – 2010, which is mainly funded by State Nuclear Waste Management Fund VYR and Technical Research Centre of Finland VTT. The results of this part of the RAKEMON project will also be used as a part of IAEA coordinated research programme on advanced, surveillance, diagnostics and prognostics techniques used for health monitoring of systems, structures, and components in nuclear power plants.

To confirm the proper operation of the pilot monitoring system it needs to detect the changes in the indications originally detected in the inspected pipe. With more advanced methods even the changes in material itself could be detected and the remaining lifetime of a component could be estimated. Only a real grown crack will behave like a real crack in a real component and therefore thermal fatigue cracks made by Trueflaw were chosen for these pilot monitoring system tests. Use of EDM notches in this case was rejected since their use would severely limit the reliability and representativeness of the test results. Indications from the EDM notches are very different from the ones that come from the thermal fatigue cracks and also the behaviour at elevated temperatures would differ from the real defects. It is understood that using realistic defects from the start will give an advantage when the pilot monitoring system is finally ready for power plant scale tests.

The measurements with pilot system will be started during 2009 and they will last until the end of 2010. The final results will be published as a VTT research report and they will also be used and reported as a part of the IAEA CRP final report.

### **Ringhals Alloy 600 repair**

Ringhals ordered a test block from Trueflaw to verify the feed water nozzle safe-end inspection. Crack sizing using TOFD was qualified. In this case, the inspection was done from ground pit with depth of 3.9 mm. Inspection was performed from the cracked side. Inspection was performed by WesDyne TRC.

It was decided to use Trueflaw cracks, to avoid any welding to the specimen. Trueflaw manufactured three cracks to Inconel 600 mock-up provided by the client. As per normal Trueflaw procedure the case required manufacturing of validation cracks, which were destructively examined to reveal the true crack depth. After production of validation cracks, cracks of known size could be produced.

By mutual discussions, it was decided, that Ringhals would do initial qualification with the validation cracks. The NDE results of the initial qualification on the validation cracks showed that the inspection procedure can meet the inspection target and set tolerances (Table 1).

Destructive depth	Inspection depth
3.2 mm	2.9 mm
2.5 mm	2.3 mm
2.3 mm	2.6 mm

Table 1 - Inspection results on TOFD sizing of Inconel 600 cracks

### NOK qualification projects

Nuclear Power plant Beznau (NOK) in Switzerland has a huge NDT inspection qualification program started last year. During this program, NOK decided to use realistic cracks in most of the cases. The main reason for selecting realistic cracks was to avoid any additional measurements and technical justification to show that the applied inspection techniques would also work on cracks. Also any discussions on the relevance of the qualifications due to unrealistic defects used were avoided.

NOK ordered several test samples from Trueflow to do inspection qualification. In this paper, two cases are presented: baffle bolts of the pressure vessel internals and RPV bolts. Former was for ultrasonic inspections and the latter for eddy current inspections. Totally there has been more than 20 Baffle bolts and four RPV bolts where cracks have been produced. Part of the work is still ongoing, but currently totally about 90 cracks have been produced during these two project cases. Sample geometries are shown in Figure 4 for both cases.

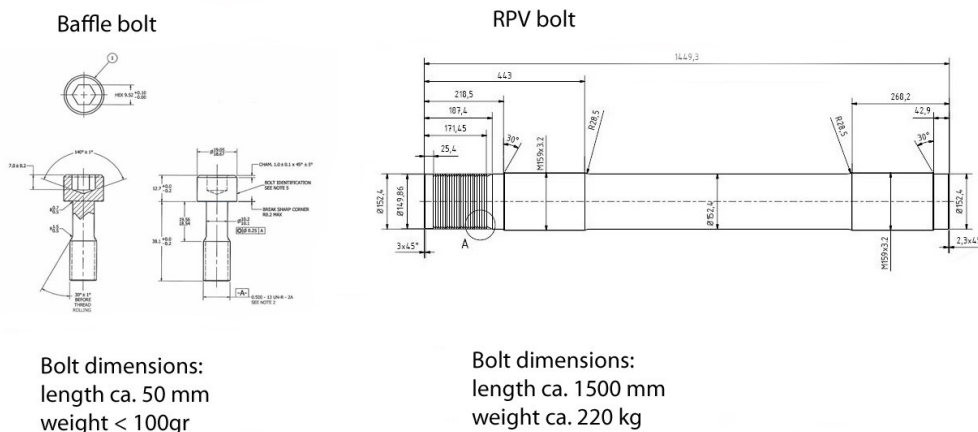


Figure 4 - NOK test pieces for the Baffle bolt and RPV qualification

For all cases, the project has followed similar process: first technical applicability was evaluated in cooperation with the supplier and NOK. Then set defect sizes were validated with full report of the destructive validation results and validation was accepted by the client. Finally, the actual cracks were produced to the open and blind test samples.

The work is still ongoing and the final results are not available yet. There may be more information published after the qualifications have been done and analyses of the procedures performed.

## CONCLUSIONS

In conclusion, the use of the more advanced defect manufacturing techniques is often beneficial. It gives inspectors more experience on real cracks and allows tuning the procedure to find and size real cracks. The test blocks would be more generic and could be used for various NDT methods and procedures. Using grown cracks reduces re-work when methods or requirements change or new information becomes available.

Clear guidelines for justifying used defects and requirements for defects are needed in the ENIQ to promote efficient use of different flaw types and efficient use of gained experience.

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## REFERENCES

- 1) Chapman, B., Seldis, T., Eriksson, A. (Eds.) *European Methodology For Qualification Of Non-Destructive Testing, Third Issue*. ENIQ report nr. 31, EUR22906EN, Luxemburg, Office for Official Publications of the European Communities, 2007. ISSN 1018-5593
- 2) Eriksson, A., Whittle, J. (Eds.) *ENIQ Recommended Practice 1, Influential / Essential Parameters, Issue 2*. ENIQ report nr. 24, EUR21751, Luxemburg, Office for Official Publications of the European Communities, 2005
- 3) Lemaitre, P. (Ed.) *ENIQ Recommended Practice 2, Recommended Contents for a Technical Justification*. EUR 18099 EN, Luxemburg, Office for Official Publications of the European Communities, 1998
- 4) Lemaitre, P. (Ed.) *ENIQ Recommended Practice 3, Strategy Document for Technical Justification*. EUR 18100 EN, Luxemburg, Office for Official Publications of the European Communities, 1998
- 5) Lemaitre, P. (Ed.) *ENIQ Recommended Practice 4, Recommended Contents for the Qualification Dossier*. EUR 18685 EN, Luxemburg, Office for Official Publications of the European Communities, 1999
- 6) Lemaitre, P. (Ed.) *ENIQ Recommended Practice 5, Guidelines for the Design of Test Pieces and Conduct of Test Piece Trials*. EUR 18686 EN, Luxemburg, Office for Official Publications of the European Communities, 1999
- 7) Lemaitre, P. (Ed.) *ENIQ Recommended Practice 6, The use of modelling in inspection qualification*. EUR 19017 EN, Luxemburg, Office for Official Publications of the European Communities, 1999
- 8) *ENIQ Recommended Practice 7, Recommended General Requirements for a Body Operating Qualification Of Non-Destructive Tests*. EUR 20395 EN, Luxemburg, Office for Official Publications of the European Communities, 2002
- 9) Chapman, R., Chapman, V., Eriksson, A., Simola, K., Waites, C., Whittle, J. (Eds) *ENIQ Recommended Practice 8, Qualification Levels and Qualification approaches, Issue 1*. EUR 21761 EN, Luxemburg, Office for Official Publications of the European Communities, 2005
- 10) Cueto-Felgueroso, C., Simola, K., Gandossi, L. *ENIQ Recommended Practice 9, Verification and Validation of Structural Reliability Models And Associated Software To Be Used In Risk-Informed In-Service Inspection Programmes*. EUR 22228 EN, Luxemburg, Office for Official Publications of the European Communities, 2007

- 11) Kemppainen, M., *Realistic artificial flaws for NDE qualification – novel manufacturing method based on thermal fatigue*, Dissertation for the degree of Doctor of Science in Technology, Espoo, Finland, 2006. (Available online from: <http://lib.tkk.fi/Diss/2006/isbn9512282631/>)
- 12) Virkkunen, I., Kemppainen, M., Ostermeyer, H., Paussu, R., Dunhill, T. " Grown cracks for NDT development and qualification", *InSight*, 2009 5, *to be published*
- 13) Paussu, R., Virkkunen, I., Kemppainen, M., "Utility aspect of applicability of different flaw types for qualification test pieces", *6th International Conference on NDE in Relation to Structural Integrity for Nuclear and Pressurised Components, Oct 8 th – Oct 10th. Budapest, Hungary. 2007*
- 14) Packalén, T., Sillanpää, J., Kemppainen, M., Virkkunen, I. and Paussu, R., "The influence of the crack opening in the UT inspection qualification", *6th International Conference on NDE in Relation to Structural Integrity for Nuclear and Pressurised Components, Oct 8 th – Oct 10th. Budapest, Hungary. 2007*
- 15) Kemppainen, M., Virkkunen, I., Packalén, T., Sillanpää , J., Paussu, R. "Importance of crack opening in UT inspection qualification", *6th International Conference on NDE in Relation to Structural Integrity for Nuclear and Pressurised Components, Oct 8 th – Oct 10th. Budapest, Hungary. 2007*
- 16) Wåle, J., Ekström, P. *Crack Characterisation for In-Service Inspection Planning*. SKI-project 14.4-940389, SAQ/FoU report 95/07, SAQ Kontroll Ab, Stockholm, Sverige. 1995
- 17) Hänninen, H. Hakala, J., "Pipe Failure Caused by Thermal Loading in BWR Water Conditions", *International Journal of Pressure Vessels and Piping*, Vol 9, pp. 445-455
- 18) Tapani Packalén, private communication