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RECOMMENDED PRACTICE

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The Use of Modelling in Inspection Qualification

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FOREWORD – BRIEF REVISION HISTORY OF RP6

The first issue of ENIQ Recommended Practice 6 (RP6) was produced by the former ENIQ Task Group 2.2 and was published in December 1999. The second issue of RP6 was published in 2011. The technical development in the areas of modelling, software and computer performance allows for using modelling in new areas and in advanced ways. This third issue of RP6 reflects this evolution. It also introduces changes resulting from best practices in today's modelling.

EXECUTIVE SUMMARY

This Recommended Practice (RP) has been developed as a consensus document amongst the members of NUGENIA Technical Area 8 (TA8) - ENIQ. The main objective of this RP is to advice inspection vendors and NDT engineers on how to use modelling to develop inspection techniques and on how to use modelling results in technical justifications. It also supports licensees and qualification bodies to assess modelling results if they are used in a technical justification. The document includes descriptions of models and provides examples on how they can be used as part of substantiation of an inspection. Restrictions in using modelling and measures which should be applied are also addressed.

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1. Introduction

The European Methodology Document [1] [2] is intended to provide a general framework for the development of qualifications for the inspection of specific components to ensure they are developed in a coherent and consistent way while still allowing qualification to be tailored in detail to meet different national requirements.

Modelling is capable of providing significant support to technical justifications (TJs). The production of TJs is discussed in detail in ENIQ Recommended Practice (RP) 2 - Strategy and Recommended Contents of TJs [3]. This RP will assist those who are involved in design or assessment of TJs in which computer modelling is used for generation of theoretical evidence. This RP is relevant for any Non-Destructive Testing (NDT) method.

2. Objectives

The main objectives of this RP are to:

- Inform about types and range of available models;
- Show various applications of simulation in qualification, training, data analysis, etc.;
- Show how models can be used to generate evidence for a TJ;
- Show how models can be used for training and qualifying NDT personnel;
- Analyse important considerations and constraints in using models;
- Justify the need of validation of models used;
- Justify the need of training in modelling.

Notes:

- The general definitions in the ENIQ Glossary [2] apply to this RP.
- Today, most of the modelling codes are dedicated for several inspection techniques such as ultrasonic, electromagnetic and radiography techniques. However, it is intended that this RP and general principles which it introduces are relevant for any NDT method. This is an important issue due to extensive evolution and recent application of new NDT techniques, such as computed radiography, digital radiography, guided waves and others.

3. Available Types of Models and Their Applications

The purpose of modelling is to generate quantitative and qualitative predictions about aspects of inspection performance through the use of mathematical models of the physical phenomena on which the NDT technique under consideration is based. Normally the mathematical model is implemented as a computational model although some mathematical models may be amenable to hand calculation using simple mathematical formulae or implementation in spreadsheets. In the following the focus is on the computational models and corresponding software codes, which will be referred to as “models” and “codes”.

A wide range of models have been developed to meet the various inspection requirements. Some models aim to fully simulate the inspection process. The input data of such models comprise basic information such as characteristics of the defect, component, working environment factors and the choice of the NDT technique (method, physical phenomena) which together make up the description of the inspection and their output represents the output inspection results. Other models are focused on one aspect of the inspection process, e.g. the computation of an excitation field, the calculation of reflection coefficients, the homogenisation of a heterogeneous or composite structure and the estimation of corresponding effective parameters (attenuation, permittivity), etc. Concerning the implementation of these models in codes the following types of codes can be distinguished:

- NDT oriented in-house codes developed by the end user;
- Commercial NDT packages; and
- General simulation packages (commercial or in-house) such as finite element codes that are applied to solve NDT-related issues.

Common applications for these codes related to ultrasonic inspection are:

- Calculation of ultrasonic ray paths or wave fields in components of complex geometry, possibly including reflections off postulated defects;
- Predicting echo amplitudes from postulated defects as a function of probe position and orientation; and
- Predicting ray paths or wave fields in anisotropic and possibly inhomogeneous material such as an austenitic weld metal, possibly including reflections of postulated defects.

For eddy current inspection common applications are:

- Predicting impedance variations from postulated defects with probe position and frequency, in plate, tube and other geometries; and
- Predicting electric and magnetic field distributions.

For radiographic inspection common applications include:

- Determination of optical density variations from postulated defects;
- Calculation of build-up factors; and
- Examining the effect of changing source, exposure and set-up parameters.

For any inspection method, the codes may be also used to:

- Perform parametric variation studies in order to investigate the behaviour of an inspection system response due to variation of one or more essential parameters;
- Generate probability of detection (POD) curves;
- Generate virtual inspection data for training and examining personnel; and
- Improve the understanding of inspection results.

4. Use of Modelling in Technical Justification

4.1 Advantages of Using Modelling

Modelling can be an attractive option for generating evidence on inspection capability for TJs. It has four key advantages over the alternative approach of performing experiments on test specimens: speed, cost, versatility and invariance of experimental error.

The speed and cost advantages are clear. Running a model is generally much quicker and more cost efficient than manufacturing and inspecting test specimens. This is especially true if realistic defects are required in the test specimens, rather than simple reflectors such as notches or flat-bottomed holes, provided the model is able to handle realistic defects.

The third advantage is that of versatility. A good model is able to handle a wide range of inspection parameters and possible defect positions, shapes, sizes and orientations. A test specimen, by contrast, can only include a limited number of defects, and it will not normally be possible to cover the full range of plausible defects, as defined in input parameter specification [4]. A good model can fill the gaps in the experimental results and reduce the number of test specimens needed. Provided they remain within their regimes of validity, models can also be used to extrapolate experimental data over the full range of essential parameters and so generalise experimental data.

The last advantage is that results from modelling do not include inherent variation due to experimental error or environmental influence as would be encountered with test piece trials. Sources of errors such as uncertainty in defect size and shape are also not encountered, and sources of error unique to modelling (e.g. numerical error) are typically much smaller.

Despite these advantages, modelling is rarely used alone to provide evidence for a TJ. More usually it provides one element of evidence, alongside other sources (e.g. experimental evidence, parametric studies, physical reasoning, feedback from field experience, equipment considerations) as described in other ENIQ documents [1][3][5].

Appendix 1 provides a checklist on issues that might be considered by authors of TJs when contemplating the use of modelling.

4.2 Ways of Using Modelling

There are many ways in which modelling can be used to provide evidence for a TJ. This will vary from case to case, depending on such factors as the extent of relevant experimental evidence and the availability of suitable models. In general, modelling may be used to study the effect of varying essential input, procedure or equipment parameters up to the limits of tolerance or range specified [3]. Examples of how models are currently and commonly used are:

- Prediction of signal amplitudes from postulated defects and determination of their margins of detection above the proposed threshold level and/or above noise level. In general, threshold levels are established using the responses of calibration defects (side drilled holes, flat bottomed holes, etc.);
- Quantification of the influence of influential parameters related to the inspected component, e.g. varying geometry, surface roughness, metallurgical characteristics (grain sizes, dendrite orientations, etc.), or the environmental conditions (e.g. temperature);
- Quantification of the influence of influential parameters related to the inspection system, e.g. probe parameters, excitation pulse, frequency, especially when modelling is performed of inspection with advanced techniques having a more complex setup such as Phased Array (PA) and Time of Flight Diffraction (TOFD) techniques;
- Determination of the most difficult defects to detect from amongst those in the defect specification (the “worst case” defects);
- Interpolation / extrapolation between cases covered by experimental data, in order to provide a fuller assurance of capability over the ranges of variation of influential parameters (such as defect orientation, location and size or equipment settings);
- Prediction of inspection capability for components of similar but slightly different geometry from those for which experimental data are available; or
- Providing physical insight that can be used further in technical arguments, and help to understand physical phenomena.

Whatever the model is used for, it may in some cases be necessary to correct the predictions to overcome known limitations of the model, or to allow for effects not included in the model (e.g. defect roughness or poor surface finish).

4.3 Parametric Studies and Probability of Detection curves

An attractive application of modelling is the investigation of an inspection system response following variation of one or more influential parameters, known as a parametric study. This may become an alternative to experimental parametric study, which tend to be expensive.

Parametric studies made by modelling are a useful tool for the identification of essential parameters and the investigation of effects that cannot practically be investigated experimentally, using fully representative test pieces. The results of parametric studies can be analysed in many ways. One particular method of analysis is the generation of POD curves.

If the calculated output value of a model is directly related to detection performance and if there is clear correlation between certain essential parameter (such as defect through wall extent) and detection performance, POD curves may be generated.

The generation of POD curves requires a dedicated model to be run a number of times with various sets of input influential parameters that are sampled from selected statistical distributions. The model itself is normally optimized in terms of calculation speed to enable adequate sample sizes to be generated in practical time scales. At the same time, it must be ensured that:

- Simplification of the model as a result of optimisation does not compromise the validity of the model output;
- The model used is validated for the range of variation of the input influential parameters;
- Statistical distributions selected for input influential parameters are realistic;
- In order to reach the required statistical validity, the POD is generated from a sufficient number of model calculations.

5. Use of Modelling for Training and Examining Personnel

Use of simulators in training and examining personnel is another application of modelling. The advantages of modelling (in comparison to experimental alternative) are clear. There are several ways to simulate inspection, for example flaw data can be pre-recorded on real flawed samples, or pre-calculated by modelling. The following are two examples of how modelling can be used for training or examining of personnel:

- A simulator may be used to generate the on-line response of an inspection system to manual probe movement over a virtual specimen. The simulator should be optimised in order that the output is provided in real time in response to an operator´s inputs. If it is not possible for the model to compute responses in real time it may be acceptable to simplify the model in some aspects – in most cases it is possible to simplify the model whilst providing an output that realistically captures the inspection system response to the variation in influential parameters. Simulators are often used to train and/or test an operator's skill in moving a probe to cover the inspection volume and in recording potential indications.
- A model can be used to simulate the output of an inspection system, to create a virtual test block, thus simulating data from automated inspection. The model could be used to simulate the response from defects which can be superimposed on scanned data recorded from a blank test piece, or the complete system response could be generated via simulation. In this application, the versatility of the model also becomes its greatest advantage, since it allows data to be generated and combined from various defects. This application is limited to cases when it is possible to import simulated data into data analysis software for which the person is trained or qualified.

Similarly to other modelling applications, modelling in training and examining may be complementary to experimental work on test blocks.

Use of simulators and virtual test blocks is part of Computer Based Training (CBT). This topic is also addressed in RP10 “Personnel Qualification” [6].

6. Use of Modelling in Assisting Data Analysis

A model, which is designed to simulate a specific inspection, may be used to help to interpret data from the inspection. Typical possibilities may be considered:

- Interpretation of indications caused by geometry and by various wave modes in ultrasonic inspection;
- Recognition of flaw indications in complex images;
- Iterative characterisation of defect by comparison of indication patterns to the model response for simulated defects.

Modelling, if used to assist data analysis, should be dealt with in the qualified inspection procedure.

7. Considerations and Constraints in the Use of Models

It is clearly important to use modelling with care in order to generate high-quality evidence for a TJ. Little credence can be given to model predictions if, for example, the model is based on unsound physics or is clearly being used outside its regime of validity. The following four issues should be addressed when considering the use of a model in a TJ.

7.1 Physical Basis and Regime of Validity

The crucial issue when using models is to evaluate the level of reliability of the predictions provided by the model. Great care must be taken with the relevance of the computations by considering the physical basis of the model and the domain of applicability of the model. This is especially true since simulation software models are powerful tools offering multiple possibilities and are based on sophisticated mathematical and numerical theories. In order to ensure that the model is valid for the planned range of use, the following basic aspects need to be considered:

- Are there aspects of the inspection that are not accounted for by the model?
- Does the model account for the influence of the essential parameters under investigation?
- What are the main underlying hypotheses, simplifications and approximations of the model?
- Has the model already been used or validated in the context of similar applications?
- Is the level of the validation evidence available proportionate to the importance of evidence, generated by simulation, to the substantiation of the capability of the inspection technique?

A good model is based on sound physical principles. Owing to the complexity of real inspection situations, exact analytic solutions are unlikely to be available, and approximations will inevitably have to be made in the model. Such approximations can arise either directly in the theory itself (for example, using Kirchhoff theory or the Geometrical Theory of Diffraction for ultrasonics), or in the numerical method used, e.g. discretisation in a finite difference, finite element or boundary element approach. The underlying physical principles and approximations of each model should be well-established and well documented (with appropriate references).

All models have a clearly defined regime of validity. For example, many ultrasonic models are restricted to homogeneous isotropic materials such as ferritic steel, and become invalid for anisotropic media such as austenitic welds, where the underlying equations are more complex. Another common restriction for many ultrasonic models is that defects are assumed to be smooth. Similarly, an eddy-current model may only be valid for non-ferromagnetic media (material permeability of 1), and/or for defects having no electrical contact between their faces, while a radiography model might be applicable only within a given energy range. The approximations introduced into the model to render the problem more tractable may also limit the model's regime of validity. For example, the Geometrical Theory of Diffraction, in its simplest form, is known to fail at caustics of the diffracted field. Comparison with experiment (see below) is one method of quantifying a model's regime of validity.

In most applications, model predictions should only be cited in a TJ if the model has been run within its own regime of validity. In some cases it may be possible to relax this constraint, for example by applying correction factors, but evidence is then required to justify such relaxation and the magnitudes of the correction factors used.

7.2 Representation of Input Parameters

The input parameters of a simulation generally consist of qualifying characteristics (type of probe, isotropy of the material, etc.), and values of the influential - physical parameters (frequency of the excitation, wave speed in the component, etc.). The representation of the real inspection by a set of input parameters is based on:

- Hypotheses relating to the component under test (geometrical assumptions, material considerations, etc.) or to the equipment behaviour (e.g. piston source behaviour of ultrasonic probes); and
- Knowledge of the values of the influential parameters.

Both items may involve approximations: Also uncertainties or inaccurate determination of influential parameters may have a considerable influence on the relevance of the simulated results. Thus input parameters for every simulation have to be chosen with great care.

7.3 Validation of the Model

Validation of models is typically performed by comparison of their predictions with the results of experiments. Models that have been thoroughly validated against experiments (or other established theories) and that have satisfied performance criteria are preferred, and the validation work should be referenced in the TJ. In certain cases it may be acceptable to use models in a TJ which have not been fully validated. Such models should only be used in a supporting role, to explain or support experimental results, or should be explicitly validated for the cases of interest as part of the TJ itself. This topic is further discussed in Chapter 8.

Comparisons between simulated and experimental data should always include both the validation of the model itself (and its implementation) and the validation of the idealisation of the inspection configuration.

When a code is used in a TJ (except cases when calculation is simple and elementary), it is recommended to carry out few comparisons between computed and measured data, particularly when the simulation code has been validated for similar cases only and not for the case being considered, or the value of existing validation is weak. A possible discrepancy between computation and measurement does not necessarily prohibit the use of the model in the TJ but depending on the case (and on its possible cause) it may be used to "calibrate" the model or to estimate margins of confidence. For example, if a model for an ultrasonic inspection is consistently overestimating the amplitude of defect responses by a consistent margin it may be acceptable to correct the results in many circumstances.

Generally when there is a lack of available validation data for the scope considered in the TJ it is recommended to carry out a specific validation campaign. Recommendations related to such (numerical and experimental) validation are given in Chapter 8.

Certain aspects of modelling, which are difficult to assess experimentally, might also be verified by cross code comparisons (see Section 8.2). In some rare cases, models can be validated by comparison with existing analytical solutions.

7.4 Relevant Information to be reported to the Qualification Body

Generally, in a TJ process it must be demonstrated to the qualification body that the models used have a sound physical basis, that they are used within their regimes of validity and that they have received adequate validation against experiment and/or other theories. Additional supporting evidence is necessary such as:

- The name of the code, version (the version is of particular importance when commercial codes are used), developing organization and documentation;
- Experience and training of the persons running the model;
- The input parameters of the model;
- Modelling results including their accuracy;
- Elements justifying the relevance of the model, i.e.
    - Physical basis of the model and its domain of validity;
    - Available and confirmed data related to the validation of the model for similar cases: data from the literature or resulting from international benchmarks, experimental databases, etc.;
    - Experiments carried out with the aim of evaluating the reliability and accuracy of the model under study.

As well as using their in-house models, the authors of a TJ may be considering the use of other models developed by external organisations, either by buying in the models or by contracting external organisation to run their model on the authors' behalf. In such circumstances it is very important to ensure that the model is suitable for the authors' needs. A checklist of issues to be considered when buying in or using external models is provided for guidance in Appendix A.

8. Considerations and Recommendations for the Validation of Models

As emphasized above, the availability of validation data is a key aspect for using simulation for TJ. The validation of a code or model is mainly the comparison of the results it delivers with reference results, normally from experiments (experimental validation, see Section 8.1) or from other models (numerical validation, see Section 8.2).

8.1 Recommendations for Experimental Validation

Design of Experiments

The design of experiments includes the choice or specifications for mock-ups, flaws, specimens, experimental procedures, parameter set up, etc. The design of experiments is determined by the objectives of the validation. Experiment and test piece related recommendations can be found in RP5 "Guidelines for Design of Test Pieces and Conduct of Test Piece Trials" [5]. The following recommendations should be followed in the design of an experiment with the purpose of model validation:

- The test should represent the situation of interest and the range of parameters (such as flaw size, angle beams, etc.) under investigation.
- Simplify the test as much as possible, in order to isolate the phenomena under consideration and to minimize interference with other factors which might complicate the interpretation of results. If, for example, the validation concerns only the influence of the defect size or orientation on its response, simple geometries and isotropic materials will be preferred to complex mock-ups.

- Choose specimens and mock-ups whose characteristics are measureable and well-known, which also include representative and realistic flaws that give a signal response corresponding to the object that has to be inspected and modelled.
- Verify the underlying assumed hypotheses for the suitability of the chosen specimen (geometrical and material properties such as isotropy, homogeneity, etc.).

Performance of Experiments

Concerning the experiments themselves the following recommendations should be followed:

- List all influential parameters of the experiment, determine their values and make sure that these stay within specified margins throughout the experiment;
- Check the reproducibility of the results data and report their confidence intervals;
- Make same experiment several times to ensure repeatability and confirm results;
- Perform measurements in order to determine and/or confirm the underlying hypotheses and the values of those influential parameters which are not directly controlled by the experimentalist. These are in particular:
  - Material characteristics of the mock-up, such as ultrasonic velocities, sizes and positions of flaws corresponding to the inspection situation, etc.;
  - Topology of the mock-up (profilometry);
  - Characteristics of the specimens, which are not always available especially when commercial specimens are used. In particular for specimens that are used for ultrasonic inspections, additional experiments may have to be performed in order to verify that the characteristics of the ultrasonic beam (orientation, width, etc.) correspond to the nominal values provided by the manufacturer.

Performance of Computations

Concerning the input and output data the following recommendations should be followed:

- Assure consistency between the input data of the code (pertaining to the description of the test to be simulated) and the corresponding available data from the experiment. If there is inconsistency, identify and report the missing information and all the performed operations to complement the data (extrapolation, approximations, signal processing, etc.). It appears more efficient to run simulation in parallel of the experiment so that inputs of simulation are measured and noted in real time.
- Check that the results of code and experiment are in good agreement. If these are not exactly identical, report the difference quantitatively. When any post-processing of computational and/or experimental results is performed, these operations should be reported.
- Perform computations in order to evaluate the inaccuracy induced by the uncertainties in the essential parameters. These could be performed for the maximum and minimum possible values of the parameter, for at least one representative case, or a sample of the essential parameter distribution using Monte Carlo techniques.
- List the computational input parameters (e.g. element size and mesh density for a FE model) that do not pertain to the description of the test and check the relevance of the specified values.
- When necessary, perform tests on the influence of these computational parameters for at least one representative case. Experience shows that the accuracy of the computations can depend significantly on one or several of these parameters. In such cases the recommended practice is:

  - Increase successively the level of precision of the computation until convergence of the output data is achieved within a pre-defined interval.
  - If convergence is achieved with acceptable computer resources and within acceptable computation times, the corresponding value of the computation parameter for the case of interest should be adopted for all subsequent computations.
  - If convergence is not achieved, the uncertainty of the output data should be reported as a measure of the accuracy of the simulation.
  - In all cases the values of the computer parameters should be reported.
- When necessary, evaluate the reproducibility of the computational results and report the amplitude of the "numerical noise".

Report "abnormal" behaviour of the code, which is in conflict with engineering understanding. This is an indication of bugs or inadequate use of the code.

8.2 Recommendations for Numerical Validations

Another way to evaluate the reliability of a model or a code (Code1) may be to compare its prediction results with the results provided by another code (Code2), which was previously validated using experimental data for the purpose in question. The following aspects should be taken into account:

- Agreement (within a relevant range and interval of accuracy) of the results of the two codes for the same situation is an indication for:
  - The correct implementation of the two codes, provided that they are produced independently,
  - The validity of the model (mathematical formulation and its implementation by numerical algorithm) under consideration, but only if the two models considered are different in this respect.
- If different results are obtained with the two codes the drawing of conclusions is more difficult. The causes for the differences in results might be:
  - The discrepancy between the two sets of results could be attributed to the approximations of the model or to a bug in the implementation of Code 1, but only if the validity of Code 2 has been definitely proven for the input configuration of interest.
  - In addition, the discrepancy may also be due to differences between the situations considered by the codes. A careful analysis of the input parameter sets of the two codes is necessary before conclusions can be drawn. Different definitions of the parameters fed into the two codes and different adopted conventions may make this analysis difficult to perform. This is especially the case when some of the results are obtained from the literature.
  - One of the models may not take into account some physical phenomena involved in the result. This is neither a bug nor an approximation. It is then necessary to understand clearly all physical phenomena involved and check the models used.

9. Model Users Training

Where users of a model are not intimately familiar with its operation (for example as a result of not being involved in its development), it is important that they have adequate training before making use of the model for the design or justification of an inspection technique. In the context of an ENIQ RP it is only possible to state general principles regarding appropriate training. Any organisation making use of models of NDT techniques should develop a training programme relevant to their needs.

In developing such a programme the following aspects should be considered:

- General education: The model user needs to have sufficient educational background to be able to understand the physical principles involved in the inspection method.
- Training and experience in the inspection method: The model user should have appropriate training and experience in the inspection method. While it is not necessary for model users to be trained as practitioners of the method, it is necessary that they have sufficient training in the theory of the method and experience of its application to be able to understand its limitations.
- Training in operation of the model: The model user must be familiar with the operation of the model. Depending on the quality of documentation of the model and the background of the user, familiarity may be gained by self-study or through training provided by the model provider.
- Training in application of the model: The model user must be made aware of the influential parameters which may affect the results of the inspection method and must understand the extent to which these are taken into account by the model. In particular, the model user must be made aware of the range of validity of the model with respect to the influential parameters.
- Updating knowledge: Since the modelling of inspection methods continues to evolve, model users should be given the opportunity to update their knowledge through such means as technical exchanges with model providers, study of the literature or participation in conferences.

References

[1] *The European Methodology for Qualification of Non-Destructive Testing - Issue 4*, ENIQ Report no. 61, The NUGENIA Association, 2019.

[2] *ENIQ Glossary of Terms – Issue 3,* ENIQ Report no. 62, The NUGENIA Association, 2019.

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[5] *ENIQ Recommended Practice 5: Guidelines for the Design of Test Pieces and Conduct of Test Piece Trials - Issue 3*, ENIQ Report no. 56, The NUGENIA Association, 2018.

[6] *ENIQ Recommended Practice 10: Personnel Qualification - Issue 2*, ENIQ Report no. 60, The NUGENIA Association, 2018.

APPENDICES

Appendix 1: Issues to Consider when Using Models Developed by Other Organisations or when Extending the Scope of the Model Application

The authors of TJs will naturally first turn to models, which they are most familiar with, i.e. models either developed within their own organisation or which have been procured but which have been in use for some time. The authors are likely to have a good appreciation of the strengths, weaknesses and regimes of validity of such models. Greater care is perhaps needed when considering the use of unfamiliar models. This applies whether the new model is to be bought in, or will be run on the authors' behalf by an external organisation. This Appendix provides guidance on some of the issues to raise with external organisations when considering the use or procurement of their models.

Purpose of the model
What is the main "output" of the model? What can the model be used for? Does the model include calculation of defect response or is it mainly concerned with propagation?

Input and output details
What input information is required to run the model? What output information is generated? In what form is this output generated (e.g. tabular, graphical, field plots, etc.)?

Units and coordinate systems
What is the primary unit of measurement utilised by the model? Can alternative units be used? What coordinate system does the model use? Is this coordinate system consistent with practical application?

Physical basis
What physical laws and equations is the model based on? What are the simplifying assumptions and approximations made? Is the model mainly "geometrical" (e.g. ray tracing including refraction, reflection and mode conversion at boundaries) or does it include field theory for propagation and/or scattering at defects? Does software documentation contain description of models used, their approximations and restrictions?

Regime of validity and level of accuracy
What materials can the model be used for (e.g. ferritic, homogeneous anisotropic, inhomogeneous anisotropic for ultrasonics)? What component geometries are allowed (e.g. flat plate, pipe, nozzle)? What defect types are allowed (e.g. planar, volumetric, rough, smooth, multiple, branched, embedded, surface-breaking etc., crack gapes, face contact)? What constraints are there on component or defect dimensions, defect orientation, probe type, etc.? What assumptions are made about the sharpness of crack tips?

Status of model
Mature or still under development, extent of use on practical plant problems.

System versus partial models
Is the model a full "system" model (modelling the full inspection process) or a "partial" model (modelling one specific aspect, e.g. the probe beam or the scattering by the defect)? If a partial model, how is the model output treated to relate to practical inspection problems?

Model dimensionality
How many spatial dimensions does the model have? (Two-dimensional models assume variation with two spatial co-ordinates only, with no variation in the third dimension. They are often used because they are simpler to formulate and require fewer computer resources than full three-dimensional models.) If 2D, how is the output related to 3D reality? Can “3D effects”, such as defect skew, be accommodated? Can effects due to the finite length of any defect in the third dimension be neglected?

Computer requirements
On which computer operation system is the model run on? Does it run under Windows, Linux or another operating system? What are the memory and storage requirements? Are other software packages required to run the model (e.g. CAD software or scientific routine libraries such as NAG)?

Typical run times
What are the typical computer run times for the model?

Extent of documentation
Is there a user manual or other documentation? Is there on-screen help? Are the underlying theories used in the model well-documented? If examples are provided, are they relevant to the application?

Ease of running
Does the model have a user-friendly interface? How is input data entered? How robust is the model in dealing with incorrectly entered data? Does the model provide error flags or warnings if it is used outside its regime of validity? How much training does a user require to run the model? Can the model be run by a general NDT engineer on an occasional basis, or may the model be run by specialists only?

Availability of support and training courses
Does the owner organize training courses? Is it possible to tailor training course contents to customer specific needs? Is there an environment / facility for customer support and exchange of experience?

Extent of validation against experiment
How thoroughly has the model been validated against experiment (or other theories)? Is this validation work well-documented? How relevant is the validation to the application?

Availability of model
Is the model available to buy? Is the owner willing to run the model on the customer’s behalf?

Software upgrades
Is the code regularly updated, are the recent achievements (approaches to modelling, software and operating system developments) regularly implemented?

License conditions:
What conditions would apply to the customer’s use of the model? Is the provider flexible in satisfying customers’ needs by offering:

- Permanent licence with possibility of regular upgrade;
- Limited period license on using latest version;
- Network licensing.

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ABOUT NUGENIA AND ENIQ

NUGENIA is an international non-profit association under Belgian law established in 2011. Dedicated to the research and development of nuclear fission technologies, with a focus on Generation II & III nuclear plants, it provides scientific and technical basis to the community by initiating and supporting international R&D projects and programmes. The Association gathers member organisations from industry, research, safety organisations and academia.

The activities of NUGENIA cover plant safety & risk assessment, severe accidents, reactor operation, integrity assessment and ageing of systems, structures & components, development of fuel, waste & spent fuel management & reactor decommissioning, innovative light water reactor design & technologies, harmonisation and in-service inspection & their qualification.

The European Network for Inspection and Qualification (ENIQ) is a utility driven network working mainly in the areas of qualification of non-destructive testing (NDT) systems and risk-informed in-service inspection for nuclear power plants. Since its establishment in 1992 ENIQ has issued over 50 documents. Among them are the “European Methodology for Qualification of Non-Destructive Testing” and the “European Framework Document for Risk-Informed In-Service Inspection”. ENIQ is recognised as one of the main contributors to today’s global qualification guidelines for in-service inspection. ENIQ became Technical Area 8 of NUGENIA in 2012.

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