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1. INTRODUCTION

The ENIQ European Methodology Document [1-2] contains a set of principles for the conduct of inspection qualification. It is intended that detailed systems embodying these principles should be developed by individual countries in the light of their particular technical and regulatory requirements. The ENIQ Pilot Study aims to study the process of developing detailed qualification systems by carrying out the qualification of some specific austenitic pipe welds according to the ENIQ principles. In doing this it is intended that any difficulties should be identified and solutions provided. It is also the intent that the pilot study should provide evidence that this approach to qualification is a satisfactory one.

A key feature of the ENIQ approach is that qualification is by a combination of practical trials and technical justification (TJ). Practical reasons limit the number of test pieces that can be used for inspection qualification. Therefore, test piece trials can often only provide limited information on the performance of an NDT system. The purpose of the technical justification is:

1. to overcome these limitations by citing all the evidence which supports an assessment of the capability of the NDT system to perform to the required level; it follows that a better defined confidence in the inspection is provided;
2. to complement and to generalise any practical trials results by demonstrating that the results obtained on the specific defects in the test pieces would equally well have been obtained for any other of the possible defects;
3. to provide a sound technical basis for designing efficient test piece trials;
4. to provide a technical basis for the selection of the essential parameters of the NDT system and their valid range/tolerance.

The sources of potential input to a technical justification are numerous. They include the following:

- Physical reasoning to explain the choice of inspection parameters
- Previous test piece trials
- Site inspection results where defects have been confirmed and measured destructively
- Laboratory measurements
- Theoretical modelling
- Measurements on reference test pieces, if available and relevant
- Previous qualifications (where available)
- Feasibility studies and industrialisation trials
- Description of the equipment by the manufacturer
- Experimental development results
- Parametric studies.

Section 2 of this TJ outlines the pilot study and describes the objectives of the inspection. In section 3, the input information to be available prior to the start of the qualification is briefly summarised. In section 4, the inspection procedure is briefly outlined. In section 5, an analysis of influential parameters is presented in order to identify the essential parameters. In section 6, evidence is presented in support to the capabilities of the proposed inspection procedure. The essential parameters identified in section 5 are used as a guideline for the topics on which evidence is desirable. This evidence comes from the wrought-to-wrought capability study conducted in the framework of PISC III Action 4 on austenitic steel testing and measurements done on reference test pieces with the same macrostructure as the qualification test pieces and the 1st set of ISI test pieces. In section 7, proposals for test piece trials based upon the analysis of the essential parameters are presented. Finally, section 8 lists the further steps required before the TJ can be completed. This includes all the measurements which are needed to provide further information and the way in which that information will be used.

It is stressed that the pilot study is not an industrial qualification exercise. The main purpose of this document is to show how a technical justification could be written without therefore containing all the information as would be required for an industrial qualification exercise.

It is important to note that the work done in the framework of writing this technical justification has contributed significantly to the elaboration of the following 3 recommended practices:

- ENIQ Recommended Practice 1: Influential/essential parameters [3]
- ENIQ Recommended Practice 2: Recommended contents for a technical justification [4]
- ENIQ Recommended Practice 3: Strategy document for technical justification [5].

It should be realised that this technical justification was written before these 3 recommended practices were available.

2. OUTLINE OF THE PILOT STUDY

As mentioned under Scope above, the pilot study is 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. Furthermore, it is also the purpose to test the feasibility of the European methodology. The way this will be achieved is by applying the general principles of the European methodology document to one specific example.

The example that was chosen for the pilot study is the qualification of an inspection of austenitic pipe to pipe and pipe to elbow welds. 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 recommended 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. In this way, the overall case for the inspection is a stronger one than could be provided by test pieces alone. If qualification reveals shortcomings in any aspect of the inspection, modifications will be made and the qualification will be repeated until a satisfactory inspection is achieved.

Once the inspection 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 first qualification part of the pilot study. From this comparison, conclusions will be drawn about the value of qualification in providing confidence in the inspection.
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.

3. INPUT INFORMATION

3.1 Introduction

As clearly stated in the second version of the European methodology document all necessary input information required to do the inspection qualification should be provided prior to the start of the inspection qualification. A separate pilot study document is devoted to the input information [6]. In this section the most important features of the input information are briefly outlined so that the technical justification document can be read as a stand-alone document.

3.2 Component selected for qualification and ISI simulation

The components to be inspected are counterbored austenitic pipe to pipe and pipe to elbow welds. The parent materials are wrought 304/316 austenitic steel and the welds were obtained by means of manual gas tungsten arc welding (GTAW) and manual shielded metal arc welding (SMAW).

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

- Diameter Range: 20 - 406 mm
- Thickness Range: 3.5 - 28 mm
- Weld Method: TAW and SMAW
- Weld Material: 308 and E316

The weld crown of the qualification test pieces is ground whereas the weld roots are as welded. The taper angle of the counterbore is smaller than 30°.

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: 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 SMAW
- Weld Material: unknown
- Weld crown: ground
- Weld root: as welded

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

3.3 Defect situation

For the purpose of the pilot study the following defect situations are proposed:

- 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, say 30°.

The discussion whether one has to deal with a postulated or specific defect situation is for the pilot study not relevant, although the case of the specific defects situation seems to be appropriate.

3.4 ISI objectives

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.

To ensure that no defects of this size will escape detection *and* correct sentencing, the required performance levels are as follows (see reference [6] for full details on logic behind it):

For pipe thickness < 20 mm

- Defects exceeding 25% of the wall thickness (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.

4. OVERVIEW OF THE INSPECTION PROCEDURE PROPOSED

The inspection procedure is described in detail in document ENIQ.PILOT(96)5 [7].

Here follow the main features:

- data acquisition system: RD Tech TOMOSCAN 4 channel system, software version 3.4 R16
- data analysis system: RD Tech TomoLuis analysis software version Z.3B17
- scanner: Force institute AWS-6 magnetic wheel scanner
- probes used:

  Detection, length sizing and depth sizing:

  - base material: single crystal, shear waves; *2* MHz; 49, 60 and 70 degrees;
  - weld:
    - twin crystal, compression waves, 2 MHz, 45, 60 and 70 degrees (if judged relevant information obtained with shear waves in weld will also be used),
    - embedded defects: LL-wave probe;
  - weld + base material: one 0º compression wave probe;
  - sensitivity:
    - detection: threshold referenced to a 3 mm diameter side-drilled hole reflector, as specified in Table 3 of the inspection procedure (ENIQ.PILOT(96)5), with a DAC correction for the shear wave probes. Level relative to 3 mm hole determined from measurements on 20 % through-wall PISC type A defects- see Section 6.2.4.3;
    - analysis (depth sizing): noise level.

  Depth sizing:

  - TOFD: 5 MHz, 0 degrees, wedges of 45 and 60 degrees,
  - LL probes (tandem configuration),
  - crack tip diffraction in pulse-echo.

  The inspection sequence can be found in Figure 5 of document ENIQ.PILOT(96)5.

5. ANALYSIS OF THE INFLUENTIAL PARAMETERS

5.1. Policy followed to analyse the influential parameters

The policy followed to analyse the influential parameters is given in ENIQ Recommended Practice 1 [3].

There are many parameters, which can potentially influence the outcome of an inspection. Those are the influential parameters. The list of influential parameters to be considered will depend upon the specific inspection to be qualified. In practice, it is not possible to consider all possible influential parameters.

Those influential parameters, which really do affect a particular inspection, are defined as the essential parameters and are the parameters to be considered for the qualification. A case-by-case analysis has to be performed for each particular qualification in order to identify the essential parameters.

Consideration of the influential parameters for any particular inspection shows that they can be divided into three distinct groups (see Figure 1):

- input (component characteristics, characteristics of defects to be detected and sized, etc.),
- procedure (for example probe frequency, recording level, etc),
- equipment (for example digitisation rate, horizontal linearity, etc).

The first group contains parameters, which are defined by the particular inspection problem. Their values and the range over which they can vary determine the inspection approach which is appropriate to the problem. Details of the component such as its dimensions, material and geometry are included in this group along with the parameters of the defects which need to be detected and assessed. The particular defect parameters which have to be considered depend on the NDT method being used. This group of parameters is referred to as the Input Group.

The second group of parameters includes those which are chosen to ensure that the NDT to be used is matched to the component and the defects to be sought. They follow from the value of the parameters in the Input Group. Examples of such parameters are, in the case of ultrasonic inspection, the wave modes, frequencies and beam angles chosen. The parameters are specified in the inspection procedure and one of the purposes of the technical justification is to justify the choices made and determine the resulting performance to be expected from the inspection. This group of parameters is referred to as the Procedure Group. Some of the parameters in this group can vary within a certain tolerance without affecting the outcome of the inspection. Examples are the beam angles and the frequency. A function of the technical justification may be to determine and justify the tolerance allowed for the variation of these parameters.

The requirements of the inspection procedure in turn determine the kind of equipment which is to be used to implement the inspection. Some of the parameters in the Input Group can also be important. For example, a hostile environment or the need for precision in size measurement may dictate the use of automated rather than manual scanning. The need to operate the equipment remotely from the ultrasonic transducers may require the use of long cable lengths and these can influence the performance of the equipment and so on. As with parameters in the Procedure Group, there will often be a tolerance within which the parameter will not affect the inspection. The need to ensure that the equipment parameters remain within such tolerances requires regular calibration. Those parameters which can change most rapidly require most frequent calibration. The parameters relating to the inspection equipment are included in the Equipment Group. It is important to note that there are related parameters which can appear in both Procedure and Equipment Groups for different reasons. A good example is ultrasonic beam angle. The beam angles specified in the procedure are determined by the defects which must be detected. The positions, sizes, surface topography and orientation of the defects together with the component dimensions and geometry determine the ultrasonic beam angles which are appropriate. The technical justification justifies these. These angles can vary within a limited tolerance without affecting the inspection. The technical justification should also identify these values for the tolerance. Once the basic requirements of the ultrasonic transducers have been determined by analysis of the problem, the transducers must be acquired. In use, these will wear and must be checked regularly to ensure the angle and other characteristics which might change do not deviate from the tolerances given and justified in the technical justification. It is clearly, therefore, a function of the technical justification to identify all the equipment parameters which are important and to determine tolerances/ranges for them. Calibration requirements may follow from this together with an analysis of which parameters might vary and so necessitate regular re-calibration and at what intervals.

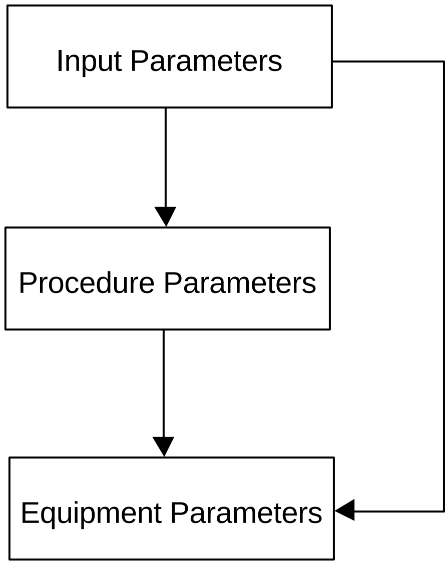

Figure 1: Different categories of influential/essential parameters

All influential parameters of the 3 groups discussed before, which do affect significantly the outcome of the inspection, will be considered as essential parameters. The influential parameters, which do not affect the inspection, are non-essential parameters and are not considered. It is to be expected that most of the influential parameters will be non-essential.

The essential parameters will be further subdivided into 2 groups, depending upon the way they will be treated during qualification (see Figure 2).

a. Essential parameters to be fixed within a tolerance

As already mentioned before, many of the identified essential parameters can sometimes vary within a tolerance without affecting the outcome of the inspection. However, if they vary beyond that tolerance they may influence the outcome of the inspection. The choice of the settings of these parameters and, if applicable, the appropriate tolerance will have to be fixed, for example, in the inspection procedure. In the technical justification it may have to be shown that the inspection is not affected as long as the value of these parameters remains within the tolerance specified. These parameters are called the "essential parameters to be fixed within a tolerance". For this first category of essential parameters it has to be ensured during qualification (technical justification and/or practical trials) that the selected settings of these parameters are within the tolerance as specified. The methods used to measure this first category of essential parameters should preferably be specified.

b. Essential parameters covering a range

The values of this second category of essential parameters have to be specified with a certain range and during qualification it has to be demonstrated that the ISI objectives can be met considering the full range specified. This can be done by either ensuring that the qualification (technical justification and/or practical trials) considers the full range specified, or by considering the limit/worst cases within the specified range of that particular essential parameter. The limit/worst cases used in this context refer always to the specific inspection situation and techniques considered. The number of essential parameters falling into this category will generally be small.

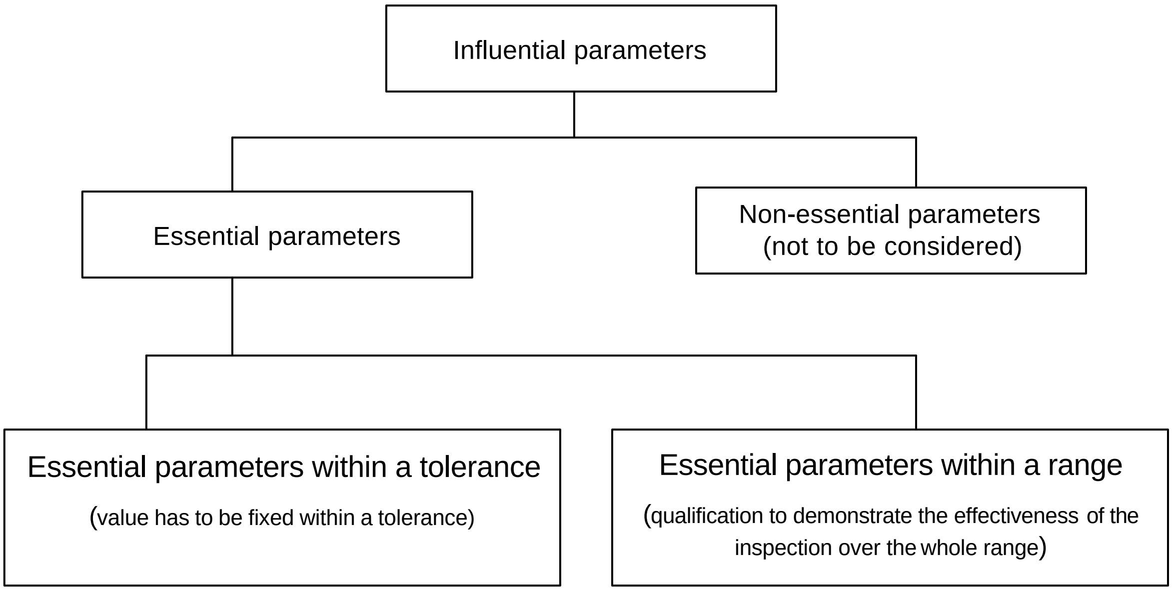

Figure 2: Classification of essential parameters according to the way they will be treated during qualification

The classification of the influential parameters into these 2 categories of essential parameters will depend upon each specific inspection qualification case. However, it is expected that most of the parameters of the procedure and certainly those of the equipment group will fall in the first category of essential parameters (to be fixed with a certain tolerance). On the other hand, it is expected that most of the input parameters will fall in the second category.

For a real qualification it is expected that the analysis of the influential parameters will lead to a number of actions such as:

- assembling existing documentation evidence (EDE) or handbooks of evidence;
- listing the necessary studies of the reasoning or modelling type to interpolate or extrapolate the knowledge to specific situations, abbreviated as reasoning and modelling evidence (RME);

- listing necessary limited practical trials on reference specimens (PTR) as additional supporting evidence;
- listing measurement methods and specifications (MMS) for the measurement of every parameter involved in the replacement/repair of components of the inspection system.

It is the intention to use PISC II and PISC III results as far as they can be applied:
- parametric studies on the importance of equipment characteristics [8],
- RRT on equipment characteristics measurement [9],
- parametric studies on the effect of defect characteristics on their detection and sizing [10-14],
- PISC III RRT results dissimilar metal welds [15-17],
- PISC III RRT results on wrought stainless steel assemblies inspection [18-19],
- effect of the counterbore on inspection performance [20],
- evaluation of inspection results along PISC III rules [21],
- {results of previous qualification exercises conducted by ENIQ members (UK, France, Sweden, Belgium,...) - to be elaborated}.

Within the framework of the pilot study it is the intention to show how this concept of influential/essential parameters can be implemented in practice. *It is stressed that the pilot study is not an industrial qualification exercise. Therefore it was not possible with the available resources to provide all necessary information as one would normally do in an industrial qualification exercise.* Furthermore there has been a lot of discussion within ENIQ at the level of Task Group 2.2 and the Steering Committee of how the issue of essential parameters should be tackled.

Parts which are not fully developed within this technical justification are:
- assembling of required additional information as detailed in the analysis of the influential parameters given in section 5.2 including the specification of measurement methods for many of the fixed parameters is not given;
- full justification of the sizing techniques used especially for what concerns the LL technique; the fact that open trials are conducted in order to assess the sizing techniques used allows to some extent to correct for this;
- full justification of the data analysis scheme as described in the inspection procedure; this issue, is, however, carefully assessed during the open trials.

5.2 Identification of essential parameters of the input group related to the component and defects to be inspected

5.2.1 Component

The list of component influential parameters considered is as follows:

C1 Geometry of the component (second part being a straight pipe or elbow): issue of single or double-sided inspection
C2 Surface conditions
C3 Weld crown configuration
C4 Weld root configuration
C5 Wall thickness of the straight pipe
C6 Diameter of the pipe
C7 Counterbore
C8 Counterbore dimensions
C9 Weld mismatch (misalignment)
C10 Macrostructure of the wrought base material
C11 Macrostructure of the weld

1. *Importance of influential parameter C1: geometry of the component (second part being a straight pipe or elbow): issue of single or double sided inspection*

   If the component is symmetric an inspection can be performed from both sides. If the component is made of a straight pipe and an elbow, there may be restrictions for a full double sided inspection.

   The geometry of the qualification test pieces and the 1st set of ISI assemblies is such that inspection from both sides is possible.

   C1 is an essential parameter to be considered within a tolerance, fixed by the input information. The qualification performed is valid only for an inspection performed from both sides of the weld.

   Note that the data acquired during the open and blind trials will allow to conduct a parametric study to verify the influence of an inspection from one side only.

2. *Importance of influential parameter C2: surface roughness*

   The surface roughness of the test pieces is smaller than 6 µm R_a. The surface roughness is such that it does not affect significantly the inspection. C2 is considered as an essential parameter to be considered with a tolerance. The qualification performed is valid provided that the surface roughness is smaller than 6 µm R_a.

3. *Importance of influential parameter C3: weld crown configuration*

The weld crown is ground. Therefore scanning over the weld is possible and mechanised scanners can be used.

Restrictions for the inspection can arise from macroscopic undulations. Profiles taken from the qualification test pieces and the first set of ISI assemblies shows that the maximum value of these undulations over a distance of 50 mm are around 3 mm. This may affect significantly the inspection performance. Therefore C3 is considered as an essential parameter to be considered within a range.

For a real qualification exercise more evidence should be assembled to study the influence of this parameter (PTR/C3, EDE/C3 and RME/C3).

4. *Importance of influential parameter C4: weld root configuration*

In the pilot study it was decided to consider the weld root as manufactured. The exact weld root configuration will affect the inspection performance. Especially the 45 degree probes used is affected by the weld root. This is less the case for 60 and 70° probes.

C4 is considered to be an essential parameter to be considered within a range. The qualification will only be valid for the weld root configurations considered in the qualification test pieces. Profiles of the weld roots were measured and are given in Appendix 1.

The length of the protruding part of the weld root varies between 0 and 30 mm and the through-wall extent of the protruding part of the weld root varies between 0 and 4 mm.

For a real qualification exercise more evidence should be assembled to study the influence of this parameter (PTR/C4 and RME/C4) and ways to quantify this parameter. It should be demonstrated that the inspection procedure could handle a normal variety of weld root configurations, typical of what is present in the plant, as the exact weld root configurations in the plant can not be measured.

5. Importance of influential parameter C5: wall thickness

The wall thickness is considered to be an essential parameter to be considered within a range, which can affect significantly the inspection performance. Therefore, C5 is considered to be an essential parameter and has to be considered during the practical trials.
The wall thicknesses considered vary between 13.5 and 30 mm. The qualification is hence valid for these wall thicknesses.

In order to better assess the influence of the wall thickness on the detection and sizing performance it would be advisable to do some measurements in test pieces covering the different wall thicknesses. Additional evidence should therefore be assembled in PTR/C5 and RME/C5

6. Importance of influential parameter C6: pipe diameter

The pipe diameters considered in the pilot vary between 320 and 700 mm. The pipe diameter affects the scanner to be mounted. It should be verified that the scanner can be mounted on pipes with the diameters considered. The limit case for C6 is the case of the smaller diameters.

C6 is considered as an essential parameter to be considered within a range. In the practical trials at least the limit cases of the smaller diameters should be considered. Evidence should be presented that the scanner can be mounted on the range of diameters considered.

7. Importance of influential parameter C7: counterbore (taper angle)

The maximum taper angle of the counterbore, considered in the pilot study is 30°. The results obtained in the framework of PISC III Action 4 on austenitic steel testing have clearly shown that most teams did not have particular problems with the counterbore (EDE/C7). Furthermore, a parametric study also conducted in the framework of the PISC III Action 4 (EDE/C7) showed that, if the taper angle is smaller than 30 degrees then the amplitude of the signals coming from defects (through-wall extent considered were 5, 10 and 20 % of the wall thickness), it is in general smaller than that due to the counterbore. In the case of the pilot study the exact position and geometry of the counterbore is known. The counterbore taper angle is considered as an essential parameter to be considered within a range with the limit case being 30°.

8. *Importance of influential parameter C8: distance of the counterbore from the weld centreline*

Two distances between the weld centre line and the counterbore are considered: 5 and 85 mm. If the counterbore is situated closely to the weld centre line then there might be problems in distinguishing the weld root from the counterbore. The distance between the counterbore and the weld centre line is considered to be an essential parameter to be considered within a range with the distance of 5 mm being the limit case considered in this pilot study.

9. *Importance of influential parameter C9: weld mismatch*

Visual observation and internal profile measurement can inform the operator on mismatch of the pipes. This may then result in a warning and will determine the discussion on this parameter. It should be demonstrated that the inspection procedure can handle a normal variety of weld mismatch configurations, typical of what is present in the plant as the exact weld mismatch configurations in the plant can not be measured.

No weld mismatch is occurring in the ENIQ pilot study test pieces and so this parameter C9 is considered to be non-essential for this pilot study.

10. *Importance of influential parameter C10: macrostructure of wrought base material*

The macrostructure of the wrought base material is considered to be an essential parameter to be considered within a range, which may affect significantly the inspection performance. Ultrasonic measurements done on reference test pieces confirm that the detection and sizing of PISC type A defects present in the base material are possible. Some of the qualification assemblies will be examined destructively allowing to document this issue more in detail.

In the framework of the pilot study measurements have been done on reference test pieces (see section 6). These show that very clear ultrasonic signals are obtained for side drilled holes (diameter of 2 mm) in the base material and for PISC type A defects of 20 % and 40 % through-wall extent with *2* MHz shear wave probes.

The quantification of this essential parameter is not easy. Two types of measurements can be considered:

- ultrasonic measurements such as for example the signal-to-noise ratio measured on Φ 2 mm side drilled holes with the probes used in the inspection procedure (attenuation measurements, as will be shown in section 6, are relatively unreliable);

- macrostructure (grain size, orientation, etc.); this will be done during destructive examination after the open and blind trials.

This issue of quantification of this essential parameter should be studied in more detail (PTR/C10).

11. *Importance of C11: structure of the weld material*

The structure of the weld material affects significantly the inspection performance and is therefore an essential parameter to be considered within a range. Characterisation of the weld structure is not always easy, as already discussed. Possible means are:

- details of manufacturing process,
- ultrasonic measurements (attenuation, measurements on reference test pieces),
- macrostructure.

In the framework of the pilot study, measurements have been done on reference test pieces (see section 6). These show that very clear ultrasonic signals are obtained for side drilled holes (diameter of 2 mm) in the weld and for PISC type A defects of 20 % and 40 % through-wall extent with 2 MHz compression wave twin crystal probes.

For what concerns the discussion on the quantification of this essential parameter, the reader is referred to what was said on this issue for C10. A similar study as for C10 should be done (PTR/C11).

5.2.2 Defects

The list of influential parameters to be discussed is based upon the PISC exercise:

D1 Shape of the defect
D2 through-wall extent of the defect
D3 Position of the defect along the through-wall extent of the component
D4 Position of the defect along the axis of the component
D5 Tilt angle of the defect
D6 Skew angle of the defect
D7 Roughness/branching of the defect
D8 Presence of residual stresses

1. *Importance of influential parameter D1: aspect ratio of the defect*

   The shape of the defect (or aspect ratio) is considered to be an essential parameter to be considered within a range, due to the sizes considered for the through-wall extent. The defect shape has to be postulated. Furthermore, analysis of data in EDE/D1 can be used to define limit cases, which is in fact the circular shape (aspect ratio 1 to 1).

2. *Importance of influential parameter D2: through-wall extent of defect*

   It is clear that the defect through-wall extent is an essential parameter to be considered within a range and has to be considered in the test piece trials. For depth sizing crack tip diffraction should be used.

3. *Importance of influential parameter D3: position of the defect through the wall thickness of the component and ligament*

   This influential parameter relates especially to non-surface-breaking fatigue defects starting from pre-existing manufacturing defects. The position of the defect through the wall thickness and the ligament can affect significantly the inspection performance. Therefore D3 is considered as an essential parameter and should therefore be considered during the test piece trials.

4. *Importance of influential parameter D4: position of the defect with respect to the weld centre line*

   It is clear that the position of the defect with respect to the weld centre line (weld, heat affected zone, counterbore area) affects the inspection performance significantly. This has been clearly shown in the wrought-to-wrought capability study conducted in the framework of PISC III Action 4 (EDE/D4).

   Therefore, D4 is clearly an essential parameter to be considered within a range and has to be considered during the practical trials. Limit cases will be considered for both IGSCC and fatigue cracks, which are partly in the weld and the heat affected zone.

5. *Importance of influential parameter D5: defect tilt angle*

   The tilt angle is considered as an essential parameter to be considered within a range. The maximum tilt angle considered in he input information is 30°.

In documents EDE/D5.1 (PISC II parametric studies) and EDE/D5.2 (modelling) evidence can be found on “limit cases” for specular reflection, corner effect and problems due to wave mode transformations. These documents, however, consider the case of thick walled ferritic components and their applicability to the pilot study is therefore limited.

The NDT procedure foresees the use of probes with angles of incidence of 45°, 60° and 70°. With the selected angles of incidence the limit case for detection is a tilt angle of 0° because this represents the case of maximum misorientation.

More practical and modelling/physical reasoning work (RME/D5) would be welcome to study influence of the tilt angle.

6. *Importance of the influential parameter D6: skew angle*

The skew angle is considered as an essential parameter to be considered within a range

The maximum skew angle considered in the pilot study is 10°. The limit case for what concerns skew for detection, depth and length sizing is hence 10° because of the largest possible misorientation.

7. *Importance of influential parameter D7: roughness of defect*

The roughness of the defects is considered as an essential parameter to be considered within a range. In general, roughness increases the reflectivity of a defect away from normal incidence. Therefore, the limit case for defect detection is a smooth defect misoriented to the probe beam (EDE/D7). This will be considered in the practical trials.

Branching is an important parameter especially for IGSCC. Branching may pose problems especially for depth sizing. Exact quantification is difficult. In a real qualification exercise the information obtained through field experience would be valuable to define, if possible at all, limits. Extent of validity of simulation of IGSCC used in the practical trials will have to be determined a posteriori through destructive examination after the practical trials.

More work is required to provide complementary information on his essential parameter (PTR/D7).

8. *Importance of influential parameter D8: presence of compressive stresses*

   It is generally known (EME/D8) that the presence of compressive stresses makes the detection and sizing of planar defects very difficult, if not impossible. In that case it is also not possible to qualify. In the pilot study the case of absence of compressive stresses is considered. Therefore D8, is considered to be a non-essential parameter.

9. *Importance of influential parameter D9: defect position in plan*

   This parameter is only essential if there are obstructions, which limit the circumferential scanning. In the case of the pilot study that is not the case. Therefore, this parameters is considered to be non-essential in so far as that the qualification is only valid for the case where there are no obstructions limiting the circumferential scanning.

5.3 Identification of essential parameters of the NDT procedure group

The following influential parameters are considered within the NDT procedure group:

P1 wave mode
P2 probe size
P3 frequency
P4 beam angle
P5 pulse length
P6 focal characteristics of twin crystal probes
P7 sensitivity for scanning and recording
P8 scanning step
P9 scanning speed
P10 personnel training, experience and qualification
P11 sizing method

Parameters P1 toP9 are considered to be essential within a tolerance and the qualification is only valid for the values and the tolerances specified in the technical justification and the NDT procedure. Parameters P10 and P11 are considered as essential parameters to be considered within a range.

1. *Importance of influential parameter P1: general features of probes (type of waves and number of crystals)*

   Under general features is understood the type of waves selected and the number of crystals considered (single or twin crystal). If a certain type of probe has been selected, then these general features are easy to respect. In case of the pilot study the selected probes for the inspection are specified in Table 2 of the inspection procedure (ENIQ.PILOT(96)5.

2. *Importance of influential parameter P2: dimensions probe*

The dimensions of the probe can affect the coupling of the probe with the surface depending upon the radius of the pipes used.

In the case of the pilot study, all probes with a width larger than 15 mm will be profiled to fit the 406 mm diameter reference specimen.

3. *Importance of influential parameter P3: frequency*

The frequency is considered to be a parameter to be fixed in the NDT procedure. In the case of the pilot study the frequencies of the probes to be used are selected and justified through measurements on reference specimens (see section 6).

For the purpose of this pilot study the range of variation of this parameter was taken equal to the tolerance for the corresponding equipment parameter T1 (± 10 % of the central frequency).

Note: There may be other cases where the imposed range is larger than the imposed tolerance for the corresponding equipment parameter.

4. *Importance of influential parameter P4: beam angle*

Beam angles considered for detection purposes are 45°, 60° and 70°, covering quite a wide range of beam angles. The beam angle is considered as a essential parameter to be fixed with a certain tolerance in the NDT inspection procedure. The choice of the angles is justified in section 6.

For the purpose of this pilot study tolerance of this parameter was taken equal to that of the corresponding equipment parameter T3, the probe shoe angle (± 2°).

Note: There may be other cases where the imposed tolerance is larger than the one imposed for the corresponding equipment parameter.

5. *Importance of influential parameter P5: pulse length*

The pulse length of the probes is considered to be essential parameter to be considered within a tolerance. Its value and tolerance should be fixed in the NDT procedure and justified in the technical justification.

The pulse length of TOFD probes should be smaller than 200 ns. Such values are necessary to size ligaments to an accuracy of 1 mm.

For other probes the pulse length should be smaller than 5 cycles. In MMT/P5 a measurement method should be made available.

6. *Importance of influential parameter P6: focal characteristics of twin crystal probes*

P6 is considered as an essential parameter to be considered within a tolerance. Its value and tolerance should be fixed in the NDT procedure. The focusing depth of the twin crystal probes should be selected as a function of the wall thickness of the pipes to be inspected.

If the focusing depths are selected within the following range, then this covers the wall thicknesses considered in the pilot study:

45°: 25-35 mm
60°: 15-25 mm
70°: 10-15 mm

For the purpose of this pilot study the range of variation of this parameter is taken equal to the tolerance of the corresponding equipment parameter T5, the twin crystal probe focal characteristics.

Note: There may be other cases where the imposed tolerance is larger than the one imposed for the corresponding equipment parameter.

7. *Influence of influential parameter P7: the sensitivity used for scanning, detection threshold and analysis of the indications*

Parameter P7 is considered to be a tolerance essential parameters, to be fixed in the inspection procedure and justified in the technical justification. Measurements have been done on reference test pieces in order to determine the optimum values for the sensitivities to be used (see section 6)

8. *Influence of the influential parameter P8: scanning step*

The scanning step is considered as tolerance essential parameter to be fixed in the NDT procedure. The scanning step selected for the ENIQ pilot study should be smaller than 2 mm both in X and Y. This ensures that the scanning step is smaller than 20 % of the smallest beam width.

9. *Importance of influential parameter P9: scanning speed*

The scanning speed is considered as a tolerance essential parameter to be fixed in the NDT procedure. The scanning speed will not exceed 50 mm/sec. This guarantees that all signals will be acquired with sufficient resolution.

10. *Importance of influential parameter P10: personnel training, experience and qualification*

The influential parameter P10 is considered as an essential parameter to be considered within a range and to be tested during the practical trials. The required evidence for the personnel training, experience and qualification has to be made available. Furthermore, the personnel is to be tested during the blind trials.

In this respect it is noteworthy to mention the following:

1) It is not possible to master human errors of a qualified operator in a qualification procedure. Human errors can only be avoided by implementing a rigorous quality assurance system involving also invigilation. This should then allow to master factors such as traceability of data, documents and certificates, management of documents, replacement of personnel, etc.

2) In order to avoid as much as possible dependence upon expert judgements the NDT procedure should be defined and described in detail as far as possible. Furthermore during open trials it is verified whether the data interpreter can give satisfactory explanation for the obtained inspection results. The purpose of the blind trials is then to verify whether the operator applies correctly the NDT procedure qualified previously during the open trials.

If what is said under points 1) and 2) functions correctly then human factors can be reduced as much as possible. Note that in a real inspection quality control methods such as verification of data and audit are applied to reduce the effects of human factors.

11. *Importance of influential parameter P11: sizing method*

The sizing method to be used has to be specified in the NDT procedure. It is considered as an essential parameter to be considered within a range.

Note that the sizing performance to be achieved should be justified in the technical justification and is verified in open and blind trials.

5.4 Identification of essential parameters of the NDT equipment group

The influential parameters of the NDT equipment group are classified in different categories:

- hardware pulser/receiver and data acquisition (E-parameters)
- cable (L-parameters)
- transducers (T-parameters)
- scanner (S-parameters).

5.4.1 Hardware pulser/receiver and data acquisition

The following influential parameters are considered:

E1 vertical linearity (screen height)
E2 horizontal linearity (time base)
E3 resolution of digitiser
E4 sampling rate
E5 averaging rate
E6 points per A-scan sampling
E7 pulse amplitude of the emitter
E8 pulse width of the emitter
E9 pulse fall time of the emitter
E10 pulse rise time of the emitter
E11 bandwidth of receiver
E12 available gain of receiver
E13 band pass filter of receiver
E14 time base setting pulse echo probes
E15 time base setting TOFD probes
E16 sampling gate

The setting of all of these parameters is given in the document on the inspection procedure [7]. They are all considered as essential parameters to be considered within a tolerance.

One of the main conclusions of the PISC II parametric study on equipment characteristics (EDE/E1.1) was that, if a correct calibration and checking is performed, most of these parameters remain within such boundaries as not to affect significantly the inspection performance.

The linearity for the first 2 parameters is checked according to TRC procedure TI-11P-15 (see reference 4). Furthermore, the inspection system is checked and calibrated according to the RD Tech procedure PTOMO 34 revision B, at least once a year (see reference 4).

A possible problem may arise from the fact that the methods used to measure all these parameters are not well documented (see reference EDE/E1.2 for a discussion on this topic). Therefore, measurement methods of the hardware parameters of data acquisition must be well documented to avoid discrepancies and should be part of the qualification dossier (MMS/E1-E15).

If a part of the hardware has to be replaced then all calibrations should be done in order to verify that the settings of the equipment are within the limits, as defined before.

5.4.2 Cable

Influential parameters are:
L1 cable length
L2 impedance.

The cable length used and its impedance are considered as essential parameters (within a tolerance) to be specified in the NDT procedure (see EDE/L1). It should not be changed during an inspection (see EDE/L1). If it is required to measure the cable impedance the measurement method should be documented fully (MMS/L2).

5.4.3 Probe

Once the NDT procedure has been defined and the different choices have been made as described in section 5.2 it will be necessary to acquire the probes. In order to be able to acquire in a correct way the probes a number of essential hardware parameters of the probes have to be fixed and known with a certain accuracy within the tolerance as specified for the procedure essential parameters. This aspect is also important in view of replacement of nominally the same probes. This implies that it is important that the measurement method of each of these essential parameters, fixed in the equipment group is specified.

It is important to note that there are related parameters which can appear in both the Procedure and Equipment Groups for different reasons, as was explained in section 5.1.

Essential parameters to be fixed (value and tolerance) for the probe are:

T1 probe frequency
T2 probe index
T3 beam shoe angle
T4 probe shoe angular deviations (squint angle)
T5 twin crystal probe shoe focal characteristics

1. *Importance of influential parameter T1: probe frequency*

   This equipment parameter is very closely related to procedure parameter P3.

   The central frequency of the probes selected should be within 10 % of the given nominal frequency, as considered during the PISC parametric studies (EDE/T1). T1 is considered as an essential tolerance parameter. The measurement method is to be given in MMS/T1.

2. *Importance of influential parameter T2: probe index*

   The exact value of the probe index has to be fixed in the NDT procedure. The probe index of each probe should be measured before the start of each inspection. After each inspection the probe index should be measured again. If the difference is larger than ± 2 mm, this should be taken into account for the evaluation of the inspection results.

   T2 is considered to be an essential parameter to be considered within a tolerance (tolerance ± 2 mm) and the measurement method should be specified (MMT/T2).

3. *Importance of influential parameter T3: probe shoe angle*

   This parameter T3 is closely connected to procedure parameter P4.

   The angle of incidence of the shear wave probes should be within a tolerance of ± 2° of the nominal value. The angle of incidence of the dual beam compression wave probes (detection, sizing LL probes and pulse-echo) varies with the depth and should lie within ± 3° of the nominal angle (taking into account the depth).

   For TOFD beam angles of 45° and 60° are used, depending on the wall thickness of the component. For TOFD, the exact value of the beam angle does not affect significantly the inspection performance. Nevertheless, the angles of incidence selected for TOFD should be specified in the inspection procedure and the tolerance should be respected for quality assurance requirements.

T3 is considered to be an essential parameter to be considered within a tolerance (tolerance ± 2° for shear wave probes and ± 3° for twin crystal compression wave and TOFD probes) and the measurement method should be specified (MMT/T3).

4. *Importance of influential parameter T4: probe shoe squint*

The squint angle of the probe has to be known and limited to less than 2 degrees for the thickest components used (EDE/T4). A squint angle measurement method is given in MMS/T4.

T4 is considered to be an essential parameter to be considered within a tolerance (tolerance ± 2°) and the measurement method should be specified (MMT/T4).

5. *Importance of influential parameter T5: twin crystal probe shoe focal characteristics*

Under twin crystal probe shoe focal characteristics we understand the virtual focus dimensions and the focusing depth of the probe. This equipment parameter T5 is closely related to procedure parameter P6.

For an industrial qualification exercise it is mandatory to specify a method to measure the focusing depth of the probe and the virtual focus dimensions of the probes (MMS/T5).

Tolerances must be small if one wants to replace probes without additional trials to be documented in EDE/T5. Additional evidence should be obtained from a parametric study on the influence of the variation of the virtual focusing depth of twin crystal probes (PTR/T5). The proposed tolerances are:

- focal depth: +/- 5 mm
- focal spot: +/- 3 mm.

Additional evidence should be obtained from a parametric study on the influence of the variation of the virtual focus dimensions of twin crystal probes (PTR/T5) in order to complement the evidence for EDE/T5.

T5 is considered to be an essential parameter to be considered within a tolerance

Note: For equipment parameter T5 clearly more work is required which is outside the scope of this pilot study

5.4.4 Scanner

The scanning device is important to be considered due to the lack of reproducibility it may introduce.

- capability of detection and sizing depends upon:
  - the scanning speed
  - the scanning step (separation between adjacent scans);
- repositioning of the scanner can result in non reproducible results;
- scanning in parallel or orthogonal way to the defects can be different if the scan plan is not correct; this case is not applicable to the pilot study as only scanning parallel to the defects is considered.

The following procedure parameters concerning the scanner were already considered
P8 scanning step
P9 scanning speed.

The one remaining parameter is the linearity of the scanner, influential parameter S1. The linearity of the scanner will be checked before each inspection using TRC procedure TI-11P-30 (MMS/S3). S1 is considered as an essential parameter to be considered within a tolerance.

5.4.5 Identification of essential parameters of data display and analysis system

The data display software has to be capable of constructing B-, C- and D-scans from the recorded A-scans whereas the analysis software has to be capable to make all necessary measurements on the obtained images. All this has to be done in a reasonable time so that the memory capacity of the system has to be sufficiently large.

The data display and analysis system is considered as a tool to be used for the analysis. The decision tree for analysis of the inspection data should specify which kind of images are used during the different steps of analysis. The analysis scheme used should be justified in the technical justification and tested during the open trials. It is considered as an essential parameter covering a range.

{For the purpose of the pilot study it has not been possible to develop this paragraph in more detail; in a real qualification exercise this will be necessary.}

5.4.6 Measurement and calibration interval

All of the parameters mentioned in this section 5.5 should be measured/calibrated at least before each inspection round. Some of these parameters will be measured/calibrated more regularly (before the inspection of each weld) as described in the inspection procedure (document ENIQ.PILOT(96)5).

5.5 Real in-service conditions (environmental factors)

The in-service boundary conditions should be part of the input information to be provided prior to the start of the qualification and should be considered during the qualification. The main purpose is to demonstrate that the qualified inspection system achieves the same performance as demonstrated during the qualification. Possible means of verifying this could for example be by imposing requirements for accreditation of the inspection vendor along EN 450001 of by performing specially designed tests to verify some essential parameters identified.

This issue was not pursued further in detail in the framework of the ENIQ pilot study because of limited resources but it is stressed that it is recognised that this is an important issue to be considered. In general, the environmental factors are essential parameters to be considered within a range.

5.6 Overview of essential parameters identified

In Tables 1 to 5 a summary is given of the discussion of the different essential parameters. For each essential parameter, the main characteristics are specified. The decision whether to consider it as an essential parameters within a tolerance or covering a range is also given. Furthermore, additional evidence, available or to be made available, is also mentioned. In the last column, the tolerance/range is given for the parameters in the input and procedure group. For the parameters in the equipment group the tolerance is given in this last column. If necessary, also some comments are given in this last column.

Table 1: Influential parameters of the input group related to the component

Influential parameter	Nr.	Additional evidence	Type of essential parameter	Range of variability/comments
Geometry of component; double sided inspection	C1		Tolerance	Inspection from both sides
Surface roughness	C2		Tolerance	< 6.3 µm R_a
Weld crown configuration: - presence of macroscopic undulations - ground	C3	To be done: PTR/C3, RME/C3 and EDE/C3	Range	Less than 3 mm over a surface of 50 mm x 50 mm
Weld root configuration	C4	To be done: PTR/C4 and RME/C4	Range	- not ground: * length: 0- 30 mm * through-wall extent: 0-4 mm - profiles as given in Appendix 1
Wall thickness	C5	To be done: PTR/C5 and RME/C5	Range	13.5 - 30 mm
Pipe diameter	C6		Range	320 - 700 mm
Counterbore taper angle	C7	Available: EDE/C7	Range	< 30 degrees
Position of counterbore along pipe axis	C8	Available: Measurement of internal profile	Range	5 and 85 mm
Weld mismatch (bad adjustment or ovalisation)	C9		Non-essential	It is postulated that no weld mismatch is present for this case

Macrostructure base material	C10	• to be documented as far as possible • destructive examination a posteriori • to be done: PTR/C10	Range	Grain size and macrostructure to be determined a posteriori through DE
Macrostructure weld	C11	• to be documented as far as possible • destructive examination a posteriori • to be done: PTR/C11	Range	Grain size and macrostructure to be determined a posteriori through DE

Table 2: Influential parameters of the input group related to the defects

Influential parameter	Nr.	Additional evidence	Type of essential parameter	Range of variability/comments
Defect shape	D1	Available: EDE/D1	Range	Smallest aspect ratio considered is 1 to 1 (postulated)
Defect size	D2		Range	- 3 mm - 100 % through-wall extent - qualification defect size is 50 % TWE (fixed by fracture mechanics and safety factor)
Defect position along through-wall extent of pipe and ligament	D3		Range	Fatigue defects starting from pre-existing manufacturing defects
Defect position with respect to weld centre line	D4	Available: EDE/D4	Range	- fatigue cracks: weld - IGSCC: HAZ and base material - limit case: partially HAZ and weld
Tilt angle	D5	- available: EDE/5.1 and EDE/5.2 - to be done:: RME/D5	Range	< 30°
Skew angle	D6	- available: RME/D6 and EDE/D6 - to be done:: RME/D6	Range	< 10°
Roughness/branching	D7	To be done: EDE/D7, PTR/D7	Range	- determined by defect type - limit case of smooth planar defect is to be considered
Presence of compressive stresses	D8	Available: EDE/D8	Non-essential	Considered to be small in this component
Defect position in plan	D9		Non-essential	No obstructions limiting the circumferential scanning

Table 3: Procedure influential parameters (see also section 6 for justifications of choices made)

Influential parameter	Nr.	Characteristics	Type of essential parameter	Range/comments
General features	P1	- type of waves: shear and/or compression - - twin or single crystal	Tolerance	- fixed in the inspection procedure - justify choice in the TJ
Dimensions probe	P2	For width larger than 15 mm will be profiled to 406 mm reference specimen	Tolerance	- fixed in the inspection procedure - justify choice in the TJ

Frequency	P3	Defined using reference specimens
		• detection:
		  - 2 MHz for twin crystal compression wave probes
		  - 2MHz for shear wave probes
		• sizing:
		  - TOFD: 5 MHz (base material)
		  - LL: 3 MHz
		  - pulse-echo: 2 MHz
			Tolerance	- choice and tolerance to be fixed in the inspection procedure and to be justified in the TJ
				- tolerance: taken equal to tolerance of parameter T1 (± 10 % of the central frequency)

Beam angle	P4	• detection: 45º, 60º and 70º
		• sizing:
		  • TOFD:
		    - T < 20 mm: 45º
		    - T > 20 mm: 60º
		  • LL:
		    - Tr 47º, Re 31°
		    - Tr 68º, Re 45º
			Tolerance	• choice and tolerance to be fixed in the inspection procedure
				• tolerance: taken equal to tolerance of parameter: T3:
				  - shear wave probes: ± 2°
				  - twin crystal probes (detection + LL): ± 3°
				  - TOFD probes: ± 3°

Pulse length	P5	- pulse echo (detection and sizing) +LL: < 5 cycles - TOFD: < 200 ns	Tolerance	- choice and tolerance to be fixed in the inspection procedure - range: see characteristics

Beam focal characteristics of twin crystal probes	P6	• focal depth: • detection: - 45°: 25-35 mm - 60°: 15-25 mm - 70°: 10-15 mm • LL: - 47º/31°: 25 -30 mm - 68º/45º: 10-15 mm	Tolerance	- choice and tolerance to be fixed in the inspection procedure and to be justified in the TJ - tolerance: taken equal to tolerance for parameter T5 - focal depth: ± 5 mm
Sensitivity used for recording and reporting level and analysis	P7	Probe dependent - recording level defined in table 3 of ENIQ.PILOT(96)5 -reporting level is 50 % of recording level - analysis (depth sizing) is done at noise level	Tolerance	- choice to be fixed in the inspection procedure and to be justified in the TJ - tolerance: ± 3 dB (see Table 3 of ENIQ.PILOT(96)5), to be checked before the inspection of each weld
Scanning step	P8	Smaller than 2 mm	Tolerance	- choice to be fixed in the inspection procedure and to be justified in the TJ - tolerance: see characteristics
Scanning speed	P9	Smaller than 50 mm/s	Tolerance	- choice to be fixed in the inspection procedure and to be justified in the TJ - tolerance: see characteristics
Personnel training, experience and qualification	P10	- certification along EN 473 - appropriate experience and training - pass with success qualification	Range	- justify choice in technical justification - performance to be verified during blind trials
Sizing method	P11	- TOFD - LL-probes - pulse echo	Range	• to be specified fully in NDT procedure • justify choice in technical justification • performance to be verified during open trials

Table 4: Equipment influential parameters related to data acquisition hardware and software, probes and scanner (it is to be noted that all measurement methods specifications will no be made available in the framework of this pilot study)

Influential parameter	Nr.	Type of essential parameter	Additional evidence/ measurement methods	Tolerance/comments
Vertical linearity	E1	Tolerance	- available: EDE/E1.1 and EDE/E1.2 - MMS/E1-14	- fixed, should be better than 1% - calibration along TRC procedure: TI-11P-15 before each inspection
Horizontal linearity	E2	Tolerance	MMS/E1-14	- fixed, should be better than 1% - calibration along TRC procedure: TI-11P-15 before each inspection
Resolution of digitiser	E3	Tolerance	MMS/E1-14	Fixed at 8 bit
Sampling rate	E4	Tolerance	MMS/E1-14	Frequency dependent, fixed in the inspection procedure, see table 3 of ENIQ.PILOT (96)5
Averaging rate	E5	Tolerance	MMS/E1-14	Detection: rate fixed at 4 TOFD: rate tolerance at 16
Points per A-scan sampling	E6	Tolerance	MMS/E1-14	Tolerance, maximum number depends on sampling rate and gate length
Pulse amplitude of the emitter	E7	Tolerance	MMS/E1-14	Probe dependent, tolerance in the inspection procedure, see table 3 of ENIQ.PILOT (96)5
Pulse width of the emitter	E8	Tolerance	MMS/E1-14	Probe dependent, fixed in the inspection procedure, see table 3 of ENIQ.PILOT(96)5
Pulse fall time	E9	Tolerance	MMS/E1-14	Fixed at 7 ns
Pulse rise time	E10	Tolerance	MMS/E1-14	Fixed at 15 ns
Band width of receiver	E11	Tolerance	MMS/E1-14	Fixed, 35 MHz
Available gain of receiver	E12	Tolerance	MMS/E1-14	0 – 92 dB
Band pass filter of receiver	E13	Tolerance	MMS/E1-14	Fixed in the inspection procedure, see table 3 of ENIQ.PILOT (96)5

Time base setting pulse echo probes	E14	Tolerance	MMS/E1-14	± 10 % of original value (to be checked before the inspection of each weld)
Time base setting TOFD probes	E15	Tolerance	MMS/E1-15	± 0.5 mm (to be checked before the inspection of each weld)
Sampling gate	E16	Tolerance		Probe dependent, defined in table 3 of ENIQ.PILOT(96)5
Cable length	L1	Tolerance		Fixed length
Cable impedance	L2	Tolerance	MMS/L2	± 5 Ohms
Probe frequency	T1	Tolerance (see P3)	MMS/T1	± 10 % of the central frequency
Probe index	T2	Tolerance	MMS/T2	± 2 mm
Probe shoe angle	T3	Tolerance	MMS/T3	Detection: - ± 2 degrees for shear wave probes - varies along depth for twin crystal probes; should be known within ± 3 degrees TOFD: tolerance of ± 3°
Probe shoe squint angle	T4	Tolerance	MMS/T4	± 2°
Twin crystal probe focal characteris-tics	T5	Tolerance (see P6)	- to be done: EDE/T5 and PTR/T5 - - MMS/T5	Focal depth: ± 5 mm Focal spot: ± 3 mm
Linearity of scanner	S1	Tolerance	MMS/S1	Calibration along TRC procedure TI-11P-30
Data display and analysis system	D1	Range		- images to be looked at during analysis of the data to be fixed in inspection procedure: * recording of A-scans * possibility to construct B-,C- and D-scans * measurement possibilities on images * possibilities of selection of gates - data analysis scheme to be justified in TK and tested during open trials

Table 5: Parameters related to real in-service conditions (environmental factors)

Influential parameter	Characteristics	Essential in this case	Range of variability
Environmental factors	- time restrictions - restrictions due to radiation - -limited access - - temperature	Yes, to be considered covering a range	To be fixed in the input information

5.7 List of additional evidence available or to be made available

The analysis of the influential/essential parameters is not complete without further additional evidence. The additionally required evidence can be subdivided in 4 categories:

- existing data evaluation (EDE);
- listing the necessary studies of the reasoning or modelling type to interpolate or extrapolate the knowledge to specific situations, abbreviated as Reasoning and Modelling Evidence (RME);
- listing necessary limited practical trials on reference specimens (PTR) as additional supporting evidence;
- listing Measurement Methods and Specification (MMS) for the measurement of every parameter involved in the replacement/repair of components of the inspection system.

A survey follows of this additionally required evidence. However, one should realise that within the framework of this limited pilot study it was not possible to generate all this information. The purpose of this chapter is only to show a possible approach.

It should be stressed that the additional required evidence would be useful but may in some cases not be essential for a satisfactory qualification. In general, if evidence is not available or incomplete it should be acknowledged in the TJ and the qualification body needs then to decide whether to address the relevant parameters in open or blind trials.

5.7.1 Existing Data Evaluation (EDE)

EDE/C3 to be done (not in the framework of this pilot study): Effect of weld crown grinding on the inspection performance

EDE/C4 to be done (not in the framework of this pilot study): Quantification of weld root configurations in order to determine range of validity

EDE/C7	PISC III Report no. 30: "Parametric studies on the effects of the counterbore on flaw detection by UT in forged stainless steel piping", EUR 15372 EN
	PISC III Report no. 33: "Report on the evaluation of the inspection results of the wrought-to-wrought PISC III assemblies no. 31, 32, 33, 34, 35 and 36", EUR 15663 EN
EDE/D1	PISC III Report No. 8: Summary of the PISC II parametric studies on the effect of defect characteristics, EUR 12435 EN, especially Chapter 7 and results in corresponding references
EDE/D4	PISC III Report no. 33: "Report on the evaluation of the inspection results of the wrought-to-wrought PISC III assemblies no. 31, 32, 33, 34, 35 and 36", EUR 15663 EN, for the effect of flaw axial position of the defect (weld, HAZ , base material, counterbore)
EDE/D5	Effect of tilt angle - PISC III Report No. 8: Summary of the PISC II parametric studies on the effect of defect characteristics, EUR 12435 EN
	PISC III Report No. 16: "Validation of mathematical models of the ultrasonic inspection in steel components", EUR 14673 EN
EDE/D6	Effect of skew angle - PISC III Report No. 8: Summary of the PISC II parametric studies on the effect of defect characteristics, EUR 12435 EN
EDE/D7	J. Whittle, "Sizewell B power station public enquiry: CEGB proof of evidence on non-destructive testing" CEGB P13, November 1982
EDE/D8	PISC III Report no. 33: "Report on the evaluation of the inspection results of the wrought-to-wrought PISC III assemblies no. 31, 32, 33, 34, 35 and 36", EUR 15663 EN, for the effect of branching of IGSCC on the inspection performance
EDE/E1.1	PISC III Report No. 10: PISC parametric study on the effect of UT equipment characteristics (EEC) on detection, location and sizing
EDE/E1.2	PISC III Report No. 11: PISC II parametric studies, RRT on the measurement of UT instrument and probe characteristics (MITC)
EDE/L1	PISC III Report No. 10: PISC parametric study on the effect of UT equipment characteristics (EEC) on detection, location and sizing

EDE/T5 to be done (not in the framework of this pilot study): Effect of variation of twin crystal virtual focusing depth and twin crystal virtual focus dimensions (to be found or elaborated through measurements on reference test pieces in PTR/T5)

5.7.2 Reasoning and Modelling Evidence (RME)

In this paragraphs some suggestions are done for more modelling and reasoning work in order to have a more convincing analysis of the essential parameters. The resources actually available for the ENIQ pilot study did not allow doing this work.

RME/C3 to be done (not in the framework of this pilot study): the purpose of this work is to try to define the influence the weld crown configuration may have on the inspection performance. The presence of undulations may indeed decrease the inspection performance. A number of typical cases has to be defined.

RME/C5 to be done (not in the framework of this pilot study): evaluate effect of wall thickness on depth sizing for each of the probes considered and for the defects considered

RME/D5 to be done (not in the framework of this pilot study): More modelling/reasoning on the effect of the defect tilt angle in the pipe welds considered

RME/D6 to be done (not in the framework of this pilot study): more modelling/reasoning on the effect of defect skew angle in the pipe welds considered

RME/T5 to be done (not in the framework of this pilot study): modelling of the effect of variation of virtual focal depth and virtual focus dimensions of twin crystal probes

5.7.3 Additional practical trials on reference specimens (PTR)

A number of additional practical trials should be executed as a result of the analysis of the influential parameters. These additional practical trials should provide additional evidence to support the Technical Justification.

PTR/C3 to be done (not in the framework of this pilot study): Parametric study to verify effect of the weld crown configuration

PTR/C4 to be done (not in the framework of this pilot study): Study to quantify ranges of validity for weld root configurations considered in this pilot study

PTR/C5 to be done (not in the framework of this pilot study): verify sizing results of some defects in different pipe sections of 12 mm, 20 mm and 30 mm for defects situated subsurface, surface-breaking at inside and outside diameter when using TOFD and crack tip diffraction in pulse echo (done partially)

Note: - *this essential parameter is considered in the practical trials (blind and non-blind)*
- *partly done (see section 6).*

PTR/C10 to be done (not in the framework of this pilot study): study to quantify and determine range of validity of this essential parameter (macrostructure will be determined after practical trials)

PTR/C11 to be done (not in the framework of this pilot study): study to quantify and determine range of validity of this essential parameter (macrostructure will be determined after practical trials)

PTR/D8 to be done (not in the framework of this pilot study): parametric study to study influence of branching of IGSCCs on inspection performance

PTR/T5 to be done (not in the framework of this pilot study): parametric study of influence of variation of virtual focusing depth and virtual focus dimensions of twin crystal probes on inspection performance

5.7.4 Measurement Methodology Specification (MMS)

It is important that the measurement methods of the following parameters is documented and described. Within the framework of this pilot study it was not possible to give the details of how all these parameters should be measured but for a real qualification exercise it is important that this evidence is made available.

MMS/P5 pulse length

MMS/E1-E14 Measurement methodology of all these data acquisition hardware parameters should be specified

MMS/L2 cable impedance measurement and documentation

MMS/T1	probe frequency
MMS/T2	probe index
MMS/T3	probe shoe angle straight beam probes, shear wave angular probes and compression wave twin crystal probes
MMS/T4	probe shoe squint angle
MMS/T5	virtual focusing depth and virtual focus dimensions of twin crystal probes
MMS/S1	linearity of the scanner

6. EVIDENCE IN SUPPORT OF THE SELECTED INSPECTION PROCEDURE AND EQUIPMENT

6.1 Introduction

In Section 5, the essential parameters and their range/tolerance of variation have been defined. In this section, evidence will be presented to support the choices made for what concerns the selected inspection procedure and equipment.

What is used as evidence in support of the selected inspection procedure in any particular case, depends on what is available. For austenitic welds there are problems in compiling a technical justification that are not present for ferritic materials. These stem from the profound influence of the metallurgical structure in determining inspection performance. The structure, in turn, is influenced by the precise way in which components are fabricated. This means that any evidence supporting inspection performance arising from previous inspection of real or test components is very specific to the method used to fabricate those components. This tends to limit the amount of directly relevant evidence. However, sufficient is now understood about the role of structure that it is often possible to translate results from components made in a similar but not identical way to the actual case. This translation is an important function of the TJ.

Another problem with the production of evidence in support of the selected inspection procedure and equipment for austenitic materials is that theoretical models which predict the response of defects embedded in anisotropic materials are not yet available. This means that, unlike the situation for ferritic welds, we cannot predict the response of defects in austenitic welds though it is possible to use models developed for ferritic materials to predict the response of defects in isotropic parent material made from austenitic steel. Another type of model, which is useful for austenitic welds, is that which predicts the path of ultrasonic beams through the weld and its interfaces with adjacent materials. Such models are unnecessary for isotropic materials but can be invaluable for inhomogeneous anisotropic ones by predicting effects such as beam splitting or bending which can leave parts of the weld uninspected. Models of this kind can, however, only be applied when the detailed structure is known. This may not be possible for many welds in plant which were made some time ago and where details of the welding procedure are not available.

The difficulties discussed above mean that the presented evidence for austenitic welds is never likely to be as comprehensive or compelling as one for ferritic welds. In the latter case it may sometimes be possible to make such a strong case with the evidence presented that very few, if any, practical trials are needed to qualify the procedure. This situation is not likely to arise for austenitics. The reliance on practical trials will be greater and there is also the great need to justify the relevance of the test specimens used in terms of the real weld structure. The TJ therefore plays a vital role but a slightly different one in some aspects to that which it plays for ferritic materials.

Another difference between TJs for austenitic materials and those for ferritic ones is that, for austenitic welds particularly, the information needed both to finalise the inspection procedure and to complete the technical justification is not always available at the outset. Reference has already been made above to the way in which the structure of the welds to be inspected is needed to allow ray tracing models to be applied. Details of qualification test piece structures are also needed so that conclusions about the real welds can be drawn from test piece results. This information will be made available after the practical trials through destructive examination. Note that for a real qualification exercise one can not expect that the qualification test pieces are destroyed in order to obtain this information. This information could for example be obtained from separate test pieces fabricated in exactly the same conditions as the qualification test pieces.

This part of the TJ will therefore be used to justify the inspection procedure and equipment so far as is possible on the basis of information available. The initial use will be prior to the practical trials on the qualification test pieces so that the inspection procedure which is used is one in which the maximum confidence can be placed. Once the trials are over, the TJ will be further developed to justify the procedure used and will also be used to explain the overall case for the inspection which will comprise a combination of the trials results and technical evidence from the TJ.

This section of the TJ contains 2 main parts. In the first part, evidence is presented in support of the inspection procedure and equipment. This comprises:

- physical reasoning for choice of the inspection method and technique (section 6.2.1),
- results of measurements on reference test pieces (section 6.2.4),
- evidence available from the wrought-to-wrought capability study conducted in the framework of PISC III Action 4 on austenitic steel testing (section 6.2.5),
- requirements for the inspection personnel (section 6.2.6),
- evidence in support of the selected inspection equipment and scanner (section 6.2.7).

In the second part of this section of the TJ, the different essential/fixed parameters identified in Section 5 are discussed in the light of the evidence presented in order to justify the choices made for the inspection procedure and equipment. Furthermore, a summary is given of the evidence presented in support to meet the ISI objectives on the given components and defect specification.

6.2. Evidence in support of the inspection procedure and equipment

6.2.1 Physical reasoning for choice of inspection method and technique

6.2.1.1 Choice of inspection method

Following from the defect specification set out above, the first decision relates to the choice of inspection method. This must be ultrasonics for the following reasons:

- Defects can be embedded or at the inner, inaccessible, surface. This means that a volumetric inspection method is needed. Radiography and ultrasonics are the only two options capable of coping with the thicknesses involved.
- Radiography is best at detecting defects when the source is in the plane of the defect. Such conditions are not easy to achieve for defects such as IGSCC, which is usually not confined to a single plane. Moreover, even for planar defects, several shots with the source at different positions would be needed to cover possible orientations.
- A further problem with radiography is that, even if a defect is detected, it is not possible to provide any information on through-wall size, only on length.
- By contrast, ultrasonics can, in principle, detect all kinds of defects and provide the information on their size, which is needed to determine whether they are unacceptable.

For the reasons set out above, the chosen method of inspection is ultrasonics and this part of the TJ is now devoted to providing the evidence which supports the particular ultrasonic techniques chosen for this inspection given in section 4.

6.2.1.2 Choice of wave mode - parent material

Shear waves are beneficial for the inspection of the parent materials if they can be used. The reasons for this are as follows:

- Over a wide range of incident angles, shear waves, unlike compression waves, do not mode convert to other wave modes upon reflection from planar defects. This means that no energy is lost from the beam in reflection and the sensitivity to defects is thereby enhanced.
- Angled compression wave probes also generate a shear wave beam at approximately one half the angle of the compression waves. The amplitude of this spurious beam is comparable to the compression wave beam at angles of about 45° and exceeds it at larger angles. This both reduces the amplitude of the main beam and also complicates interpretation of the display because some of the signals arise from the shear beam and this has a different velocity to that of the compression beam.

- A further benefit of shear waves relates to defects, which break the far surface of the component. Here the defect forms a corner and this is a particularly strong reflector of shear waves between the angles of 35° and 55° [22]. By contrast, compression waves are not strongly reflected from such corners, making them less sensitive to surface breaking defects.

Although shear beams are to be preferred for this inspection for the reasons set out above, the results of the PISC III, Action 4 project discussed below show that there are benefits in using both wave modes for parent material inspection. Accordingly, both will be used.

However, it is possible that both wave modes may not be able to be used because the grain structure of the parent material may be too coarse or because the inspection may have to be done through the weld metal. If the grain structure is coarse, shear waves, which are affected more than compression waves, may be too highly attenuated and generate too much back-scatter which obscures defect signals. In this situation, compression waves must be used in spite of their drawbacks. It is not possible to say, a priori, whether the grain structure will allow the use of shear waves and at what frequency. This must be established by measurements on the actual materials. A number of measurements have been done on PISC type A defects and side drilled holes in reference test piece sections with the same grain structure as that of the qualification test pieces and the 1st of ISI test pieces (see section 6.2.3 for full details). These measurements show that it is possible to use shear wave probes both for detection and depth sizing in the base material.

A major complication which can arise when shear waves are used is in discriminating between signals from IGSCC and those which may arise from reflections at the weld root where the fusion face meets the bore. It is vital to know the exact position of the fusion face so that the range of the signals can be used as a means of discrimination. This is why the inspection procedure requires the weld fusion boundaries on the outside of the pipe to be clearly marked. Weld root repairs can be a major source of confusion because they lead to uncertainty in the root position.

When compression waves are used both for parent materials and for weld metal, they will be short pulse, twin crystal types. Experience has shown that these characteristics are valuable in the inspection of austenitic welds [23].

6.2.1.3 Choice of wave mode - weld metal

6.2.1.3.1 Grain boundary scattering

Austenitic welds made by the manual shielded metal arc welding (SMAW) have a coarse and anisotropic grain structure due to the epitaxial growth of columnar grains through the body of the weld. The dimensions of the grains can be comparable to or greater than the wavelength of ultrasound and so the grain boundaries scatter the ultrasonic waves strongly leading to both high attenuation and back-scatter. Shear waves are scattered more strongly than compression and the higher the frequency, the higher the scatter. These effects limit the inspection of SMAW welds to compression waves at frequencies lower than 5 MHz. Measurements on reference test pieces should show what are the best frequencies to be used

6.2.1.3.2 Effects of anisotropy

The columnar grain structure discussed above means that SMAW welds are highly anisotropic. This causes ultrasonic beams to behave quite differently from the well-ordered way in which they transmit through isotropic materials such as ferritic welds. A phenomenon known as beam skewing occurs which affects both the direction and width of the beam. Compression waves are affected less by this effect than are the conventional type of shear waves discussed so far. The latter are known as vertically polarised shear waves or SV waves. They are generated at the probe shoe/metal interface by mode conversion and their plane of polarisation is perpendicular to the metal surface. There is a second type of shear waves which are known as horizontally polarised shear waves or SH waves because the direction of polarisation is parallel to the metal surface. SH waves are less affected by anisotropy than either compression or SV waves but they are not so easy to generate. They are produced most conveniently by electromagnetic probes (EMAT's) but these devices have only recently emerged from the laboratory and are still in their infancy so far as application in the field is concerned. This is why they have not been specified for this inspection. For the reasons set out above, compression waves have been adopted for this inspection.

Depending on the weld structure, beam skewing may cause ultrasonic beams in the weld to be diverted away from certain regions. This means that such regions would not be inspected. To safeguard against this possibility, a computer programme called RAYTRAIM should be used to predict the paths of the ultrasonic beams specified for this inspection. This requires, as input, the columnar structure of the weld and this will be measured for the reference and qualification specimens. These have been made using a similar welding procedure to that used for the ISI specimens and so the structures will also be similar.

The measurements of weld structure which form the input information for RAYTRAIM will not be available until after the practical trials for logistical reasons (and if sufficient resources are made available). This means that justification of full coverage will only be available in retrospect. However, as discussed in section 6.2.4 and section 6.2.5 below, a range of beam angles will be used to ensure that an adequate response is generated for all defect orientations within the defect specification given in section 3. This also provides assurance that beam-skewing effects will not leave parts of the weld uninspected since such effects will not affect all beam angles in the same way. The results obtained in PISC III, Action 4 discussed in Section 5.4 below also provide support to the suggestion that the use of the range of beam angles planned from two directions will avoid problems of uninspected areas of the weld.

6.2.1.4 Choice of beam angles and sensitivity - parent material

Besides the frequency and the wave mode other important inspection parameters are the probe angles and sensitivities. These were chosen from considerations of the angles of the defects which might be present. In the parent material defects are IGSCC, surface-breaking with tilt angles up to 10° and skew angles up to 10°. Beams at around *45°-50°* are essential to detect defects which form a corner with the far surface of the component. They are also sensitive to facets of the defects away from the surface which are tilted at 45°. Probes at higher angles of 60° and 70° are included to detect favourably oriented facets at these angles.

Sensitivities for scanning and recording signals are set using measurements done on reference test pieces (see section 6.2.4.3). Sensitivity for shear waves is also based on the use of a DAC curve from 3 mm side drilled holes.

6.2.1.5 Choice of beam angle and sensitivity - weld metal

Beam angles and sensitivities for weld inspection are chosen in a similar way to that discussed above for parent material. In this case mainly compression waves are used as discussed in Section 6.2.3. Beam angles of 45°, 60° and 70° are used to cover the range of orientations of weld defects set out in Section 3.3.

The maximum misorientation possible is 20° for the case of a defect growing at 0° from a pre-existing manufacturing defect which is also at 0°. Both defects would have to be smooth to avoid facets at more favourable angles. A 0° smooth defect in the mid-wall of the weld therefore represents the worst case from a detection standpoint. The performance of the inspection for such defects in the practical trials will therefore be a key test of the procedure.

6.2.1.6 Choice of the depth sizing techniques

For depth sizing it is the intention to use to the maximum extent crack tip diffraction methods, because it has been shown, through among others, the PISC III Action 4 results, that they are much more reliable than amplitude drop methods to measure the through-wall extent of surface-breaking defects as considered in this pilot study.

It is the intention to use 3 different ways to detect the crack tip:
- Time of flight diffraction (TOFD)
- LL probe: tandem configuration
- pulse echo using the probes for detection after having re-scanned the zone of interest with the recording level set at noise level (10 % FSH).

In first instance TOFD will be applied. If it is not possible to detect the arc from the tip signal then the LL technique will be applied.

The LL technique uses 2 crystals placed on wedges which are positioned in a tandem configuration. The receiver is positioned in front of the transmitter. The time interval between the initial signal from the transmitter and the tip diffraction signal will be used to measure the depth of the defects. A more detailed description of the LL technique can be found in Appendix 4.

If no crack tip signal can be detected with the LL technique then the zone of interest will be re-scanned with the probes used for detection with the recording level set at noise level in order to detect the crack tip signal in pulse-echo.

If no crack tip signal can be detected at all then no depth sizing results will be provided. The 6 dB amplitude drop method is not applied because it is considered to be unreliable. Indeed, for smaller defects the dimensions found with this method will always be related to the beam width and not to the real through-wall extent of the defect.

It will be clearly indicated when presenting the depth sizing results with which method they have been obtained.

6.2.2 Attenuation measurements on qualification test pieces

We have tried to measure he attenuation of some of the qualification test pieces along the method described in the procedure guidelines [24]. For reasons of completeness, the method is repeated here.

The easiest method of measuring attenuation without making corrections for beam spreads and other factors is by comparing measurements made on the pipe material with identical measurements on a fine-grained ferritic material with approximately the same wall thickness and diameter. The range and amplitude of the following should be recorded for the pipe material and also the fine-grained ferritic material:

- The first two back-wall signals for 0° compression waves
- Signals detected at one and two full skips for shear waves.

The signal amplitudes are best measured as percentages of the full screen height. These results should be plotted on a graph of range against amplitude and the attenuation of the austenitic material should be calculated as follows. The gradients of the two lines in dB/m should be calculated. The two should then be subtracted to give a value for the pipe attenuation.

Practically it was difficult to implement this method. Problems encountered were:

- availability of ferritic test pieces with exactly the same geometry as the qualification test pieces,
- presence of the weld root made it impossible to do reliable measurements in the weld.

In order to be able to apply this method correctly one must have specimens available with well known thickness and with surfaces which are plane and parallel one to the other.

It was possible to do measurements in the base material. The following results were obtained (taking into account measurements on all qualification test pieces):

- compression waves at 2.25 MHz: attenuation of 20 to 40 dB/m
- compression waves at 4 MHz: attenuation of 40 to 60 dB/m
- shear waves at 2 MHz: attenuation of 40 to 60 dB/m
- shear waves at 4 MHz: attenuation of 60 to 80 dB/m.

It should be stressed that these measurements are not considered to be very reliable. As can be noticed from the results there was a large scatter. Note, however, that all values measured are smaller than 100 dB/m.

These measurements suggest that there are possibilities to inspect the base material with *2* MHz shear wave probes but this should be further verified and confirmed by measurements on side drilled holes and PISC type A defects.

6.2.3 Measurements on reference test pieces

6.2.3.1 Introduction

As a practical test on the effect of skewing and scattering on the detection of defects in the weld, two reference specimens have been manufactured which have the same columnar grain structure as the welds in the pilot study. The welding was done in such a way as to have a constant angle of *the orientation of the grains with respect* to the pipe axis.

Side drilled holes, PISC Type A defects and ASME type calibration notches have been inserted into the weld and base material and used to measure the detection performance of different ultrasonic probes. These measurements have been used to obtain information on the following parameters: type of waves to be used, frequency, beam angles, sensitivity, possibilities to size with TOFD and pulse-echo tip diffraction using PISC type A defects, simulating planar smooth fatigue defects.

Ease of use is also a factor to be considered. This is largely determined by the contact area of the probe since small probes are easier to scan over a curved surface and maintain acoustic coupling than large probes. Large probes, however, can produce narrower beams and hence better signal to noise ratios than small probes. Probe selection is therefore a compromise between competing factors and will involve an element of judgement.

The experimental approach to probe selection described above is important for the inspection of austenitic welds with angled compression waves, since a predominant feature of these inspections is that they tend to produce a much lower signal to noise ratio than an inspection of ferritic welds with shear waves and so marginal improvements can be very worthwhile. Furthermore, the ultrasonic properties of austenitic welds are highly variable by comparison to ferritic welds and so the correspondence between reference and qualification specimens used for probe selection and the real welds is very important.

6.2.3.2 Description of reference test pieces

Ultrasonic measurements have been done on the following reference test pieces (drawings are given in appendix 2) in order to select the probes to be used:

- a section of ENIQ 4: diameter 325 mm, wall thickness 25 mm
- a section of ENIQ 6: diameter 406 mm, wall thickness 28 mm
- ENIQ assembly 64: diameter 325 mm, wall thickness *25 mm.*

The macrostructure of the weld and base material of ENIQ 4 and 6 is typical of what is found in the qualification test pieces and 1st set of ISI test pieces. The macrostructure of the weld and the base material of ENIQ assembly 64 is typical of what is found in the 2nd set of ISI assemblies.

In each of the section of ENIQ 4 and ENIQ 6 side drilled holes with a diameter of 2 mm were inserted. The side drilled holes with a length of about 50 mm were drilled at depths of T/4 and 3T/4 in the weld and the fusion line and at depths of T/4, T/2 and 3T/4 in the base material, as shown in the drawings given in Appendix 3. They were drilled parallel to the tangent of the surface.

In both reference sections 4 PISC type A defects, simulating fatigue defects, were inserted: 2 (20 and 40 % through-wall extent) in the weld and 2 (20 and 40 % through-wall extent) in the base material. The position and location of the defects is given in the drawings in Appendix 3. The aspect ratio of the defects was 1 to 5. Tilt and skew angles considered were 0º.

In addition 2 ASME type calibration notch of 10 % through-wall extent were fabricated, one on the inside and one on the outside diameter.

In ENIQ assembly 64 a very clear indication pointing to the presence of a service-induced defect, located in the base material, was used to determine the frequency of the shear wave probes to be used.

6.2.3.3 Choice of sensitivity for recording and reporting of the indications

The choice of the sensitivity for the twin crystal compression wave probes was based upon the ultrasonic signals from the 20 % through-wall extent PISC type A defects in the weld of the 2 sections of ENIQ 4 and ENIQ 6. The basic idea used was that at least 2 of the different signals obtained with the compression wave probes (LL-, TLL- and TT-signals) should at least equal to the recording level.

The same reasoning was used for the shear wave probes using the ultrasonic signals from the 20 % through-wall extent PISC type A defects present in the base material. Furthermore, a DAC curve is used for the shear wave probes.

The reporting level is set at 50 % of the recording level (corresponding with 50 % full screen height).

The gains chosen for the different probes are all about 6 dB higher than the amplitude obtained on the side drilled holes in calibration block C, described in the inspection procedure (document ENIQ.PILOT(96)5).

The methods used for depth sizing are based upon crack tip diffraction. The sensitivity used for depth sizing using crack tip diffraction methods will be the noise level set at 10 % FSH.

6.2.3.4 Results obtained in base material

The main characteristics of the probes that were tested on the reference test pieces are summarised in Table 6.

Table 6: Main characteristics of probes tested for the inspection of the base material (reference test pieces)

Number	Waves	Frequency [MHz]	Angle [º]
W49K2	Shear	2	49
MWB60-2	Shear	2	60
MWB70-2	Shear	2	70
MWB60-4	Shear	4	60
MWB70-4	Shear	4	70

The 2 PISC type A defects and all SDH's were easily detected both with the 2 and 4 MHz shear wave probes. The results obtained on the 2 PISC type A defects are summarised in Table 7.

Table 7: Summary of results obtained for 2 PISC type A defects in base material (ENIQ 4)

Probe number	PISC type A defect 20 % through-wall extent		PISC type A defect 40 % through-wall extent	
	Detected	Crack tip (pulse echo)	Detected	Crack tip (pulse echo)
W49K2	Yes	Detected	Yes	Detected
MWB60-2	Yes	Detected	Yes	Detected
MWB70-2	Yes	Not detected	Yes	Not detected
MWB60-4	Yes	Detected	Yes	Detected
MWB70-4	Yes	Not detected	Yes	Not detected

Some A-, B- and C-scan images, illustrating the results discussed above, can be found in Appendix 5.

The area containing the indication in ENIQ assembly 64 was inspected with the following probes:

- shear waves, 4 MHz, 60º
- shear waves, 2 MHz, 60º
- shear waves, 4 MHz, 45º
- shear waves, 2 MHz, 49º

The indication was clearly visible with the 2 MHz shear wave probes but was not detected at all with the 4 MHz probes, as is shown clearly in the A-, B- and C-scans given in Appendix 5.

6.2.3.5 Results obtained in weld metal

The characteristics of the probes that were tested to inspect the welds of the reference test pieces are summarised in Table 8.

The shear waves probes allowed detecting all SDH's in the nearest fusion line.

The use of the TRL compression wave probes showed the importance of profiling the probes to the outside surface of the test pieces in order to obtain an adequate coupling. Furthermore, the water supply for coupling should be done by preference through holes in the probes. Nevertheless, the twin crystal compression wave probes allowed detecting all SDH's both in the fusion line and in the weld.

Table 8: Main characteristics of probes used for the inspection of the weld

Type	Waves	Frequency [MHz]	Angle [º]
W49K2	Shear	2	49
MWB60-2	Shear	2	60
MWB70-2	Shear	2	70
MWB60-4	Shear	4	60
MWB70-4	Shear	4	70
TRL 45 focusing depth 30 mm	Compression	2	45
TRL60 focusing depth 20 mm	Compression	2	60
TRL70 focusing depth 12 mm	Compression	2	70

Table 9 gives a summary of the results that were obtained with the different probes on the PISC type A defects.

Table 9: Summary of results obtained for 2 PISC type A defects in weld (ENIQ 4)

Probe type	**PISC type A defect 20 % through-wall extent**		**PISC type A defect 40 % through-wall extent**	
	Detected	Crack tip (pulse echo)	Detected	Crack tip (pulse echo)
W49K2	Not used	Not used	Not used	Not used
MWB60-2	Yes	Not detected	Yes	Not detected
MWB70-2	Yes	Not detected	Yes	Not detected
MWB60-4	Yes	Not detected	Yes	Not detected
MWB70-4	Yes	Not detected	Yes	Not detected
TRL45-2	Yes	Not detected	Yes	Detected
TRL60-2	Yes	Not detected	Yes	Detected
TRL70-2	Yes	Not detected	Yes	Not detected

6.2.3.6 Results obtained to measure the through-wall extent of the defects

TOFD was applied to investigate the possibilities to size the through-wall extent of the PISC type A defects in the base material and in the weld.

The characteristics of the probes used for TOFD are as follows:

- Panametrics, 0º, 2.25 and 5 MHz, compression waves, crystal diameter of 10 mm
- Plexiglas wedges with an angle of 45º and 60º were used.

Measurements showed that it was possible to size the 2 PISC type A defects in the base material with TOFD at both 2.25 and 5 MHz. For what concerns the PISC type A defects in the weld, it was not possible to size the through-wall extent with TOFD with the 2 selected frequencies. That is why the choice was made to take only the 5 MHz probes for sizing in the base material.

Lack of time did not allow to test the LL-techniques proposed before the open test piece trials. The experience gained by the industrial vendor assisting the Reference Laboratory in other qualification projects was used to apply these techniques.

Note: For a real industrial qualification exercise it would be mandatory to show through measurements on reference test pieces the possibilities/limitations of these LL-techniques.

From Table 9 it can be deduced that the 49° 2 MHz shear wave probe allowed to detect crack tip diffraction in pulse echo of the 20% and 40% through-wall extent PISC type A defects in the base material. The 60° 2 MHz shear wave probe allowed to detect in pulse echo crack tip diffraction of the 40 % through-wall extent PISC type A defect.

From Table 9 it can be deduced that the 45° and 60° twin crystal compression wave probes allowed to detect in pulse echo the crack tip of the 40 % through-wall extent PISC type A defect in the weld.

6.2.3.7 Evidence to support the analysis/evaluation scheme as detailed in the inspection procedure

The measurements on the reference test pieces should also provide supporting evidence that the evaluation/analysis scheme as proposed in the inspection procedure can be followed correctly allowing one to arrive to meet the ISI objectives. Within the framework of this pilot study, due to the limited resources, it has not been possible to do this work. However, one of the major objectives of the open trial results is exactly to verify this issue.

6.2.3.8 Conclusions from measurements on reference test pieces

The measurements done in the weld of the reference test pieces show that clear signals can be obtained with 2 MHz twin crystal compression wave probes for 2 mm diameter side drilled holed and PISC type A defects. Furthermore, these probes also allowed obtaining crack tip diffraction signals from a 40 % through-wall extent PISC type A defect.

The measurements done in the base material of the reference test pieces *have shown* clearly that it is necessary to use 2 MHz shear waves in the pipe material for detection and sizing, especially when considering the second set of ISI assemblies. Note that for the 1st set of ISI assemblies also 4 MHz shear wave probes could be used.

The measurements on the reference test pieces confirm that TOFD provides excellent results for depth sizing in the pipe material. The results obtained for the weld were not as convincing, however. In that case pulse-echo crack tip diffraction methods should be used, which, as was shown by the measurements on the reference test pieces, present possibilities for the larger defects.

6.2.4 Supporting evidence from wrought-to-wrought capability study conducted in the framework of PISC III Action 4 on austenitic steel testing

6.2.4.1 Introduction

Strong support for the capability of an inspection can arise from round robin trials in which the same or similar techniques have been applied to test pieces which are similar to the welds in question and contain pertinent defects. The most notable round robin trial of this kind for wrought austenitic welded components is that carried out under Action 4 of the PISC III programme [18-19]. In this trial, 23 teams applied a variety of ultrasonic techniques to 6 wrought to wrought austenitic welded assemblies. Not all the techniques are relevant to the procedure to be used in the pilot study. However, some are very close and others contain elements of the pilot study procedure. Consequently, many of the results obtained are very useful in providing evidence on the capability of the procedure to be used for the pilot study.

The defect types in all the 6 assemblies used in the round robin are given in Table 10.

Table 10: Defect types present in the 6 assemblies of the wrought-to-wrought capability study of PISC III Action 4

Defect Type	Number	Position	Size Range
IGSCC parallel to weld	10	HAZ	9 - 82% T
IGSCC normal to weld	2	HAZ	15, 26% T
Thermal Fatigue	2	HAZ	37, 61% T
Mechanical Fatigue	2	Counterbore	25, 30% T
EDM Notches	7	CB - 4 HAZ - 1 Weld - 2	3 - 18% T 2% T 16, 25% T
Embedded Notches	2	HAZ	5, 18% T
Lack of Root Penetration	1	Weld	12% T

All defects were surface breaking except for the 2 embedded notches. All were in the HAZ or counterbore region except for two of the EDM notches and the lack of root penetration which were in the weld. The defect positions are therefore relevant to the pilot study. Some, such as IGSCC and fatigue cracks, are directly relevant to those listed in the defect specification in Section 3 above. The notches simulate smooth defects such as mechanical fatigue and are therefore also of value.

Five of the welds were made by automated GTAW rather than the SMAW technique used in the pilot study. The other was made by manual SMAW and GTAW. It will therefore be necessary to produce information on grain structures for both the PISC welds and the pilot study welds before the similarity of grain structure can be established. However, this will only affect those defects in the weld or inspected through the weld and not those in parent material, inspected through parent material. For parent material defects, attenuation measurements will be used to establish similarity between the PISC and pilot study specimens.

The relevant data are extracted from the more detailed documents describing the round robin [18-19] and presented below.

6.2.4.2 Defect detection

The defects of interest in the pilot study are IGSCC in the parent material and fatigue cracks in the weld. Most of the teams who took part in Action 4 used the pulse echo technique to detect these types of defect in the pipe assemblies. Three of the assemblies contained a total of 10 IGSCC's parallel to the welding direction and the overall probability of detecting these was 0.97 for defects with a through-wall extent of 30%T and larger. This important result indicates the capability of the pulse echo technique to detect IGSCC in the parent material in Action 4.

Overall, Figure 48 of Reference 11 shows that, taking detection together with false calls, only 5 teams achieved a combination of detection rate in excess of 0.8 and a false call rate of less than 0.2. Of these, 4 used a combination of compression and shear waves for detection and the fifth used ultrasonic holography. This demonstrates clearly that, of all the techniques used in Action 4, the one chosen for the pilot study achieved the necessary combination of good detection and low false calls. It is also noteworthy that these four teams using conventional pulse echo techniques outperformed those teams which used more sophisticated techniques such as phased arrays, EMAT's and focused probes used alone. Of the advanced techniques only holography performed as well.

The detailed techniques used by the four teams above are set out on pages 69 to 72 of Reference 11. In two cases the techniques used are very similar to those proposed here. In the other two, they use elements of the procedure to be used for the pilot study.

One of the pipe assemblies, number 36, contained six planar defects in the HAZ and weld region with heights ranging from 1.7% T to 23.6% T. The probability of detecting these by the majority of the 23 teams ranged from 0.48 to 0.91 but there was no correlation between detection and defect height. These defects were detected with both shear and compression waves since they were predominantly in the HAZ. This data shows that small defects can be detected by the pulse echo technique.

6.2.4.3 Defect sizing in the through-thickness direction

The defect sizing requirements given in Section 3 are very demanding in terms of accuracy and, for this reason, the TOFD technique is specified in the procedure as the first choice if it can be applied. The accuracy of TOFD for measuring the through-wall extent of defects has been found in numerous practical trials to be the equal or superior to all other methods which do not involve the use of crack tip signals. The sizing performance achieved in Action 4 by the two best teams is given in Table 11.

Table 11: Sizing performance achieved by 2 best teams in the wrought-to-wrought capability study of PISC III Action 4

Team	Mean Error [mm]	RMS Error [mm]	Mean Deviation [%T]	Number of Defects Measured
FJ	0	2.0	8	20/26
DH	+1	2.6	8.5	26/26

The RMS error in the table above indicate that an error of 10% T could be achieved on a statistical basis for pipes with wall thicknesses exceeding 20 mm. The results for pipes with smaller thicknesses are not as good. The reason why Team FJ in the table only measured 20 out of the total of 26 defects was that they could only detect crack tip signals for 20 of the defects even when the defect location was known by the team. If this situation arises in practice, alternative sizing methods will have to be used with a corresponding drop in measurement accuracy, probably to a level lower than that required.

Reference 8 contains examples of TOFD B Scans of unrectified ultrasonic signals arising from defective austenitic welds where the grain boundary scattering noise is sufficiently low for the TOFD technique to be successfully applied. Examples are also given, however, where the noise level is too high for the technique to work.

6.2.4.4 Defect sizing in the circumferential direction

The criterion for sizing in the circumferential direction (length measurement) is given in Section 3 above. This requires a RMS accuracy of 20 mm for the smallest pipe size. The defect sizing performance achieved in Action 4 is summarised below in Table 12.

Table 12: Length sizing performance achieved in the wrought-to-wrought capability study of PISC III Action 4

Team	Number of Defects Measured	RMS Error [mm]	Standard Deviation [mm]
JN	21/26	11	12
FJ	20/26	11	10

On a statistical basis, the performance of the two teams who achieved the best defect length measurement results in Action 4 meet the stipulated requirements. However, all the teams made an error of 25 mm or more in measuring the length of at least one defect out of a population of 26. Some teams made an error of this magnitude for several defects. Consequently, a criterion for individual defects would be very difficult to achieve for austenitic welds.

6.2.4.5 Probe types

Table 13 below contains the analysis of PISC III, Action 4 results on the defect detection performance of the probes used by all participating teams. The variables included in this analysis are probe type, wave mode, beam angle and frequency. The information in the table will be taken together with other data to discuss the case for the choice of probes in the inspection procedure.

Table 13: Analysis of PISC III Action 4 results for probe performance for defect detection

Probe	Team Code	Detection rate (FDF)
S-60-2	EI	1.00
S-45-2	EI	0.94
S-45-2	KM	0.92
TRL-70-2	EI	0.83
S-45-4	OI	0.80
TRL-60-2	EI	0.78
S-70-2	EI	0.56
L-45-5	OI	0.50
L-45-4	OI	0.30
TRL-45-2	EI	0.25
TRL-70-2	OI	0.20

Key: S - shear, L - Longitudinal (compression), TRL Twin Crystal Compression
45/60/70 - Beam Angle
2/4/5 - Frequency

6.2.4.5.1 Examination of pipe material

The technical justification for using single crystal *2* MHz shear waves for the detection of IGSCC is based on the following:

The above table shows clearly that 45° and 60° shear waves are the most sensitive for defect detection.

One of the conclusions of the PISC III, Action 4 report [19] concerned a detailed analysis of the results for teams EI and KM showed that conventional pulse echo techniques with 2 MHz, 45° and 60° shear waves enabled complex IGSCC to be detected. The results for Team OI showed further that this was also the case with 4 MHz 45° shear waves.

Single crystal shear waves are adequately sensitive to detect a 1 mm diameter flat bottomed hole at ranges up to one half skip distance in fine grained material at thicknesses up to 30 mm.

6.2.4.5.2 Examination of weld metal

The table above shows that 45° and 60° shear waves have the highest capability for detection. However, they also result in a very high false call rate. Furthermore, the analysis leading to the results in the table does not distinguish between detection in the parent material and the weld metal. Shear waves are affected by anisotropy to a much greater extent than compression waves as discussed above in Section 3.3. Such factors usually make the use of shear waves for weld inspection impracticable. High angle twin crystal compression wave probes have a high detection capability combined with a lower incidence of false calls and so these are specified for this inspection.

The measurements on the reference test pieces show that 2 MHz 45°, 60° and 70° twin crystal compression wave probes allow to detect and size PISC type A defect simulating smooth planar fatigue defects in the weld.

6.2.4.6 Sizing of defect through-wall extent

TOFD is applied using a pair of angled compression wave probes generating short pulses. The reasons why this is likely to be a practicable approach are as follows:

Compression waves have a higher velocity than shear waves. Consequently, the first signal to arrive at the receiving probe is the diffracted compression wave and this simplifies the analysis of the display.

A short pulse length is required to resolve the crack tip from other signals and short pulses are also beneficial in improving signal to noise ratios.

6.2.4.7 Justification of the specified beam angles

The procedure for this inspection requires beam angles of 45°, 60° and 70° for the examination of pipe material and weld. Some of these angles are likely to be more effective than others, as the table above shows. The probes with the highest detection rate were 45° and 60° shear waves followed by 60° and 70° compression waves.

Table 14 below gives the detection rate achieved in Action 4 with the probes used by team EI.

Table 14: Detection rate achieved with probes used by team EI in the framework of the PISC III Action 4 wrought-to-wrought capability study

	Shear Probes			**Compression Probes**		
Beam Angle	45	60	70	45	60	70
Detection Rate	0.83	0.78	0.58	0.25	0.89	0.69

The results for team EI are similar to those for all the participants in that the 45 and 60 shear wave probes score highly but the 60 compression probe also has a comparable performance. In both the tables above, the 45 compression wave probes have the worst performance.

To achieve the high detection probability required for the inspection it is necessary to use all the beam angles because the probability figures for each separately are insufficiently high.

6.2.5 The training and experience of personnel carrying out the inspection

The inspection will be led by an inspector with Level III qualification and several years relevant experience. Other members of the team will be qualified to Level II and must have directly relevant expertise and experience in the different aspects of this inspection. These include:

- Ultrasonic detection and evaluation of IGSCC and fatigue defects.
- Ultrasonic inspection of austenitic welds. There are no approved courses in this subject but inspectors must have attended company-based training and have relevant field experience.
- Application of the techniques proposed for defect detection and sizing. Successful completion of a formal training course and field experience is required.
- Operation of inspection equipment proposed.

All operations involving data interpretation will be performed by the relevant expert, thus ensuring the highest degree of competence. Because the overall control of the inspection is with the Team Leader, only he will be formally qualified by the process described here.

{This is an example of how evidence could be provided on the training and experience of the operators. In a real qualification exercise this will have to be documented through certificates etc.}

6.2.6 Evidence in support to the choice of the NDT equipment and scanner

6.2.6.1 The NDT equipment

The inspection system consists of the following items of NDT equipment:

- a set of ultrasonic probes mounted on a probe pan,
- a manipulator,
- a motor controller,
- a digital flaw detector comprising data acquisition hardware and software and data display and analysis software.

All the items of equipment are portable and form a complete system. A more detailed description can be found in document ENIQ.PILOT(96)5, describing the inspection procedure.

6.2.6.2 The manipulator

The manipulator can be mounted on a steel track, which fastens around the pipe. The length of the track is adjustable to accommodate varying diameters. The track is fixed to the pipe so that the scanning range of the manipulator covers the volume of pipe to be inspected. The manipulator has two axes of movement:

- An axial movement which is sufficiently long to scan all the ultrasonic beams through the volume of the weld for a distance of 2T. The speed of scanning will be constrained to below the maximum specified in the procedure.
- A circumferential movement which rotates the probe assembly through 360°. The circumferential scan will be made in discrete controllable steps, which will not exceed the beam width of any probe in the pan.

The manipulator has encoders on both axes of movement which provide information on probe position with a resolution for the X-axis better than 1.2 mm and for the Y-axis better than 1.8 mm, which will enable the requirements of the procedure to be met on defect location and sizing.

6.2.6.3 The motor controller

The motor controller accepts digital commands from the flaw detector and converts them to DC currents to power the motors on the manipulator and move it as required for scanning.

6.2.6.4 The flaw detector

The flaw detector performs the following functions:

- It provides a flaw detector to energise the probes in a defined sequence and collect the returning signals from the pipe. The returning RF signals are digitised and stored along with their range and the co-ordinates of the probe. The flaw detector has the capability to scan and record full A-scan data from up to 4 probes so it has more than sufficient capacity for this inspection.
- It controls the inspection by scanning the manipulator according to how it is programmed and collecting the data as outlined above.
- It contains software to allow the stored data to be displayed in any chosen plane. The data can be displayed as RF signals for TOFD size measurements or as rectified signals for detection purposes.
- It allows to display A-, B-, C- and D-scans for doing the analysis.

6.2.6.5 Examples of use of the NDT equipment

{In this paragraph detailed evidence could to be provided on evidence of industrial application of the NDT equipment. For the NDT equipment used in the framework of the pilot study there should be ample evidence available.}

6.3 Discussion of the essential parameters in light of presented evidence

6.3.1 Justification of the choice of the essential parameters related to the inspection procedure and equipment treated in section 5

In Table 16 an overview is given of the justification of the choice of the essential/fixed parameters in the procedure group in view of the evidence presented in section 6.2.

Table 16: Justification of choice of the procedure parameters

Parameter	Nr.	Evidence presented in TJ	Justification of choice
General features	P1	Yes	A combination of shear waves and twin crystal compression is the most promising combination as shown through physical reasoning, PISC III Action 4 results and measurement on reference test pieces
Dimensions probe	P2	Not explicitly	For width larger than 15 mm are profiled to 406 mm reference specimen
Frequency	P3 (and also T1)	Yes	• detection: with selected frequency of 2 MHz best results were obtained on reference test pieces, and confirmed by PISC III Action 4 results • sizing: - TOFD: with 5 MHz best results were obtained in base material - LL technique: with 3 MHz satisfactory results were obtained
Beam angle	P4 (and also T3)	Yes	• detection: wide range of angles (45°, 60° and 70°) was selected in order to cope with anisotropic nature of austenitic SMAW welds as shown through physical reasoning and confirmed by the PISC III Action 4 results

			• sizing: - TOFD: different angles according to covered depth - TT: different angles according to covered depth
Pulse length	P5	Not explicitly	Good engineering criteria were selected: - detection +TT: resolution of at least 0.75 mm - TOFD: resolution at least 0.5 mm
Beam focal characteristics of twin crystal probes	P6	Not explicitly	Selected as a function of the wall thickness
Sensitivity used of recording and reporting level and analysis	P7	Yes	Measurements done on reference specimens were used to determine these levels
Scanning step	P8	Not explicitly	Should be smaller than 2 mm in order to guarantee overlap of at least 20% of the sound beam in all cases
Scanning speed	P9	Not explicitly	Smaller than 50 mm/sec
Personnel training, experience and qualification	P10	Yes	See section
Sizing method	P11	Yes	See section

The data from the wrought-to-wrought capability study conducted in the framework of PISC III Action 4 show clearly that the better teams were capable of reaching the ISI objectives as specified in Section 3.

The choice of the parameters in the equipment group is specified in the inspection procedure. It should be stressed that the choice for these parameters is straightforward and does not pose any major problems.

7. DEFINITION OF THE TEST PIECES FOR THE PRACTICAL TRIALS AS A RESULT OF THE TECHNICAL JUSTIFICATION

As a result of what was discussed in the previous sections the set of test pieces to be considered for the open (and blind trials) should be designed as follows:

Component:
As a result of the analysis the essential parameters of the component the qualification will only be valid within the limits as summarised in Table 18 of this document and this especially for what concerns the following parameters: weld crown configuration, weld root configuration, wall thickness considered and grain structure of the weld metal.

Defects:

- defect position:
  - fatigue defects:
    - counterbore (angle of 0° and 30°)
    - weld (surface and non-surface breaking)
    - partially in weld and HAZ (limit case)
    - originating at fabrication defects
  - IGSCC (branched):
    - HAZ
    - partially in weld and HAZ (limit case)
- through-wall extent of defect to be considered: between 3 mm and 90 % of the wall thickness (limit cases small/large to be considered for detection and sizing)
- defect orientation
  - tilt angle:
    - 0° (limit case for detection because of maximum misorientation)
    - 30°
  - skew angle:
    - 0°
    - 10°

The detailed description of the test pieces used for the open and blind trials can be found in document ENIQ.PILOT(96)8.

The essential/fixed parameters concerning the component and the defects are given in Tables 18 and 19, respectively. In these tables it is also shown to which extent they are considered in the practical trials

Table 18: Essential parameters related to the component and extent to which they are considered in the practical trials

Essential parameter	Nr.	Range of variability	Considered in the practical trials
Geometry of component; double sided inspection	C1	Fixed	Yes, 2 elbowed specimens
Surface roughness	C2	Fixed	< 6.3 µm
Weld crown configuration: - presence of macroscopic undulations - ground	C3	Less than 3 mm over a surface of 50 mm x 50 mm	Yes
Weld root configuration	C4	• not ground • profiles as given in Appendix 1: - length: 0- 30 mm - protruding part: 0-4 mm	Yes, as welded
Wall thickness (T)	C5	13.5 - 30 mm	13.5-16-25-30 mm
Pipe diameter	C6	320 - 700 mm	320 and 410 mm (limit case of smaller diameters)
Counterbore taper angle	C7	< 30 degrees	30 degrees (limit case)
Position of counterbore along pipe axis	C8	5 - 85 mm	5 and 85 mm
Macrostructure base material	C10	Grain size and macrostructure to be determined a posteriori through DE	Yes, E308L and E316L
Macrostructure weld	C11	Grain size and macrostructure to be determined a posteriori through DE	Yes, manual GTAW and SMAW

Table 19: Essential parameters related to the defects and extent to which they are considered in the practical trials

Essential parameter	Nr.	Range of variability	Considered in the practical trials
Defect shape	D1	Ratio depth/length varying from 1 to 2 up to 1 to 10	Yes
Defect through-wall extent	D2	- 3 mm - 100 % through-wall extent - qualification defect size is 50 % TWE	Yes
Defect position along through-wall extent of pipe	D3	Fatigue defects starting from pre-existing manufacturing defects	Yes
Defect position along axis of pipe	D4	- fatigue cracks: weld - IGSCC: HAZ and base material - limit case: partially HAZ and weld	Yes
Tilt angle	D5	< 30 degrees	0° and 30°
Skew angle	D6	< 10 degrees	0° and 10°
Roughness/ branching	D7	- limit case of smooth planar defect is to be considered - simulations of IGSCC are considered	Yes

8. RECOMMENDATIONS FOR FURTHER WORK NEEDED TO DEVELOP THE TJ

As discussed above, this technical justification is a document based on the evidence currently available and within the constraints of available resources.

For what concerns the evidence provided on the capabilities of the NDT procedure and equipment it is to be recommended to do the following:

- Detailed comparison of the grain structure of the PISC III, Action 4 specimens and that of the pilot study specimens. This will be used to establish the relevance of the PISC data to the pilot study. Note that the measurements done on the reference test pieces provide confidence that the inspection procedure selected is for purpose.
- RAYTRAIM modelling. This will be used to predict the path of the different ultrasonic beams through the qualification and ISI welds to ensure that there is full coverage. It cannot be done, however, until the evidence on the grain structure above is available.

For what concerns the analysis of the influential parameters, an approach has been proposed how this issue can be tackled. In order to complete this analysis additional evidence is required as outlined in section 6.9.

Finally, the TJ will be updated to take account of the practical trials. The results obtained will be put alongside the TJ and the overall case for the proposed inspection will be set out prior to the use of the inspection method on the ISI specimens.

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APPENDIX 1

Drawings of the qualification and ISI test pieces

See document ENIQ.PILOT(96)8 in preparation.

APPENDIX 2

Profiles of the weld root and weld crown area of the different ENIQ qualification test pieces

APPENDIX 3

Drawings of the reference test pieces and defects inserted

APPENDIX 4

Description of the LL-technique used for depth sizing

APPENDIX 5

Typical examples of A-, B- and C-scan images obtained on the defects inserted in the reference test pieces

Detection

In what follows A-, B- and C-scan images are presented obtained during the ultrasonic measurements performed on reference test piece ENIQ 4.

The images shown for the shear wave probes were all obtained on the defects present in the base material.

The images shown for the twin crystal compression wave probes were all obtained on the defect present in the weld. It is also shown in these images that it is possible to distinguish the weld root signal from the defect signal by using the mode converted signals generated. More details on the exact route followed for the analysis/evaluation of the inspection data can be found in the inspection procedure (document ENIQ.PILOT(96)5).

Depth sizing

Three examples are given where the crack tip has been detected for the 40 % through-wall extent PISC type A defect.

Then follow 4 TOFD images obtained for the PISC type A defects present in the base material in ENIQ 4.

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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.

This report contains the technical justification, which was written for the first ENIQ pilot study on wrought stainless steel welds. The work to write this technical justification was done in 1996-1997 and laid the basis of the 2 ENIQ recommended practices on technical justification (recommended contents and strategy) which were published in 1998.