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A review of worldwide practice and experience in the qualification of ultrasonic inspections of nuclear components over the past two decades

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Summary

Inspection qualification is the term currently used to describe the process of independent assessment of a specific non-destructive test to ensure that it is capable of meeting its objectives. Such activities carried out on the Sizewell B reactor inspections were referred to as validation. In the USA, the term performance demonstration is used, though this is increasingly being reserved for the part of the assessment which uses practical trials, with qualification being used, as elsewhere, when the assessment process involves assembling evidence for the efficacy of an inspection from a wider variety of sources. Most qualification activity to date has been focused on nuclear plant because of the safety implications of nuclear plant failure and also because it is here that the cost of the qualification itself is in proportion to the cost of the plant and the consequences of failure.

This paper reviews worldwide practice and experience in the qualification of ultrasonic inspections of nuclear components over the past two decades. In general, qualification has been applied to in-service inspections; however, this paper includes consideration of the application of qualification to manufacturing inspections.

To date, ultrasonic inspection is the inspection method to which most qualification activity has been devoted. However, the qualification principles discussed are equally applicable to the qualification of other inspection methods.

This paper includes consideration of:

- *Sizewell B manufacturing inspections.*
- *ASME XI requirements, including Appendix VIII.*
- *European developments, particularly the European Methodology for Qualification of Non-Destructive Testing developed by the European Network for Inspection Qualification (ENIQ).*

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He is also Chairman of the PANI Management Committee investigating the reliability of manual ultrasonic inspection.

The ENIQ methodology has been adopted throughout Europe. The benefits of the ENIQ methodology are its flexibility and the requirement that qualification be developed taking into account the parameters of importance for a particular inspection. This means that it can provide confidence that an inspection can meet its objectives. The major disadvantage of the ENIQ approach is the requirement for scarce personnel skills in the physics and practice of inspection to develop and implement qualification requirements.

Manufacturing inspections can have two purposes:

(a) to ensure that any manufacturing defects that could threaten plant integrity are detected and correctly characterised so that they can be eliminated and do not enter service (fitness-for-purpose);

(b) to detect defects of any size, including those smaller than could threaten plant integrity, taken as a measure of general manufacturing quality (acceptance standards for manufacturing).

Of the two, the sizes of defects in item (a) are more easily determined in an objective way. The choice of sizes in item (b) is more subjective since they are not directly related to structural integrity issues.

Design/Manufacturing codes traditionally require any detected planar defects to be removed, independent of defect size and capability of the inspection method. This is similar to item (b) above. Such code requirements pre-date the general use of ultrasonic inspection methods in manufacturing inspections. Ultrasonic inspection during manufacture is still not an explicit general requirement in widely used Design/Manufacturing codes. Instead, typically 'volumetric' inspection will be required, with the implicit expectation that this will be based on radiography.

The objectives of ultrasonic inspections, and hence the yardstick for their qualification, needs to be defined with care. If the requirements are set too stringently, the inspection and its qualification would be over-complex. In the other direction, a lax definition of inspection requirements could lead to an inadequate inspection. Inspections should be most effective for those defects with the highest likelihood of occurrence at the sizes of concern for structural integrity. Lesser reliability is acceptable for defects with low likelihood of occurrence at sizes of concern for structural integrity, and for smaller defects. Manufacturing inspections need to detect defects and, ideally, to characterise them in terms of whether they are volumetric or planar. In practice, an important contribution to characterising a defect and determining its significance is sizing.

Terminology

Different meanings are attached in different parts of the world to certain technical terms used in this paper. These are identified below and the meaning adopted here is defined to avoid ambiguity.

Inspection

In the USA, the term inspection is used to denote the full range of inspection activities including some, such as leak or pressure checking, which are not normally considered as non-destructive testing (NDT) in the UK. The term 'examination' is used for NDT activities. In the UK and Europe, the term 'inspection' is also used for all investigatory activities, including NDT, with the precise meaning being derived from the context, for example ultrasonic inspection, radiographic inspection etc. The latter is the usage adopted in this paper.

Validation

Validation was the term adopted for the independent assessment of the Sizewell B inspections. The organisation established to carry out the work was called the Inspection Validation Centre (IVC). This term is no longer used for this activity. However, the word 'validation' is still used to describe verification, by experimental means or otherwise, that predictive methods like mathematical modelling yield accurate results.

Performance Demonstration

Performance Demonstration was adopted as a term in the USA to describe the process of independent assessment required by Appendix VIII of ASME XI. It continues to be used specifically for those activities. It has also acquired a connotation of being limited to practical assessment of inspections using test-pieces.

Inspection Qualification

Inspection Qualification is the term adopted by ENIQ to denote the process of independent assessment of inspections. It is now universally adopted in Europe for this purpose. Even ASME XI, Appendix VIII now refers to inspection qualification.

Redundancy

In the context of inspection, redundancy in this paper is used to mean independent repetition of inspections to enhance reliability[1]. This would include the combination of automated and manual inspections.

Diversity

Diversity is used here to mean the detection of defects by different, independent mechanisms. This might mean the use of different inspection methods such as ultrasonic inspection and magnetic particle inspection. It might also mean the detection of defects by different ultrasonic approaches such as pulse echo inspection at different angles or from different surfaces or some combination of pulse echo, tandem, time-of-flight diffraction inspection etc[1].

Sizewell B from its Suffolk shoreline *Courtesy British Energy Group plc*

1. Introduction

Inspection qualification is the term currently used to describe the process of independent assessment of a specific non-destructive test to ensure that it is capable of meeting its objectives. Such activities carried out on the Sizewell B PWR (Suffolk, UK) reactor inspections were referred to as validation. In the USA, the term performance demonstration is used though this is increasingly being reserved for the part of the assessment which uses practical trials with qualification being used, as elsewhere, when the assessment process involves assembling evidence for the efficacy of an inspection from a wider variety of sources. Most qualification activity to date has been focused on nuclear plant because of the safety implications of nuclear plant failure and also because it is here that the cost of the qualification itself is in proportion to the cost of the plant and the consequences of failure.

Ultrasonic inspection is the inspection method to which most qualification activity has been devoted to date. This is because of its key role in assuring the safety of nuclear plant and also because of the many parameters which influence whether it will be successful. The latter imposes a particular requirement for independent assessment to ensure it is capable of meeting its objectives because of the potential for some of these parameters to be chosen incorrectly. For these reasons, this paper focuses on the qualification of ultrasonic inspection. However, the qualification principles discussed are equally applicable to the qualification of any inspection method. Examples of where qualification has been applied to other inspection methods are given in references 12 (eddy currents) and 13 (radiography). The latter describes a capability assessment rather than a formal qualification but includes many of the steps that would be found in such a qualification.

The ultrasonic inspection measures that were adopted during the construction of Sizewell B were the most extensive ever seen on any reactor anywhere in the world. The components which had

been identified in the safety case as requiring a demonstration of 'Incredibility of Failure' (IoF) were subjected to multiple inspections during their construction and it was also a requirement that these inspections be independently verified as fit for their purpose.

Another feature of the Sizewell B inspections was that a different approach was adopted for different IoF components. The Sizewell B inspections and their assessment are reviewed in more detail in Section 2 of this paper.

In the USA, the results of the PISC exercise[2], together with other experience in failing to detect defects in operating nuclear plant, were seen as making a case for some form of independent assessment and endorsement of the inspections of certain components in nuclear plant. However, in the USA, the measures adopted need to be applicable to about 100 reactors of widely differing types and designs. This inevitably resulted in a very different approach to the one adopted for the single reactor type at Sizewell B. Also, the requirements for Sizewell B included both manufacturing and in-service inspection whereas, in the USA, the concern was for only the latter. The American approach was set out in two mandatory appendices to ASME XI, the code governing in-service inspection (ISI) of nuclear plant[3, 4]. Section 3 of this paper reviews the requirements of ASME XI and contrasts them with those adopted for Sizewell B.

At the beginning of the 1990s, the European nuclear utilities started to consider whether a European system of inspection assessment should be developed or whether it would be sufficient to adopt the ASME XI approach. These discussions resulted in the formation of the European Network for Inspection Qualification (ENIQ) and a methodology for inspection assessment (known in Europe as 'inspection qualification') was produced[7]. This has been adopted by all European nuclear utilities as the basis of their approach to this issue. Developments in ENIQ and related European developments are reviewed in Section 4 of this paper.

Finally, the different approaches to nuclear inspection and its qualification being adopted throughout the world are reviewed and discussed in Section 5. From this it is possible to assess the implications of worldwide experience for the measures that could be adopted for future plant. The emphasis is on inspections carried out during the manufacture of nuclear plant but the principles are equally applicable to in-service inspection.

2. Qualification of Sizewell B inspections

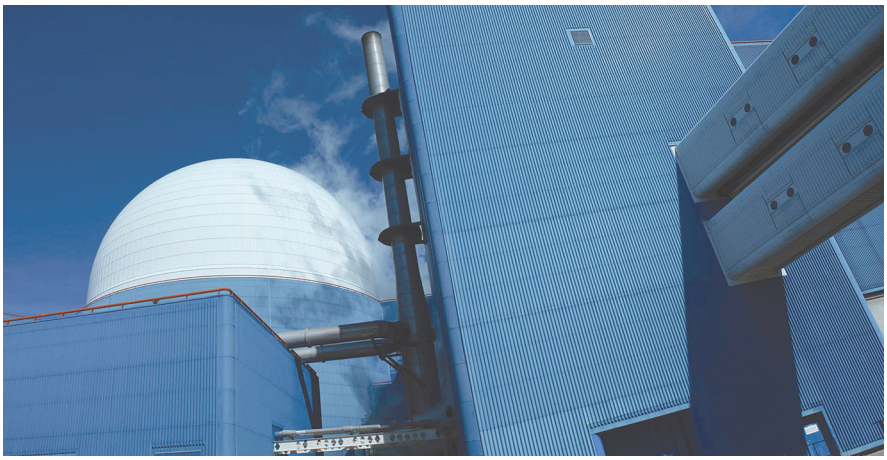
2.1 Defect specification

The need for independent assessment of the fitness-for-purpose of the Sizewell B inspections imposed a requirement that their purpose be defined in advance to provide a suitable yardstick against which they could be designed and judged. Previously, the practice had been to design inspections against the requirements of a code or standard which specified how the inspection was to be done but without reference to any particular defects. However, in the case of ultrasonic inspection in particular, the outcome of the inspection is critically dependent on certain parameters of the defects to be detected, positioned and sized. These include size, shape, position, orientation and the roughness of the reflecting surface of the defect. Unless the inspection is designed with these parameters in mind, it will probably fail. This was the reason for the abysmal results of the standard procedure used in the PISC 1 trials[2]. The inspection was based on the requirements of ASME V and contained no measures designed to detect the large, smooth, through-wall defects in the test-pieces and so the result was inevitable. Better-designed procedures produced good results on the same test-pieces.

A consequence, therefore, of the requirement for independent assessment of the Sizewell B inspections was the need to define the defects which were the objectives of the inspections together with their key parameters. This was the first time such a need had been recognised and its implementation posed difficulties as a result. There was no body of knowledge on which to draw because the information now judged to be necessary had never been required before. If the requirements were set too stringently to make up for lack of information, the inspection designed to detect and size the defects would be over-complex. This could be counter-productive and actually reduce the reliability of the inspection. In the other direction, a lax definition of defect requirements could lead to an inadequate inspection for the defects which might actually occur in practice. A realistic and comprehensive defect specification was, therefore, crucial for the Sizewell B inspections.

The principle adopted for Sizewell B was that the inspections should be most effective for those defects with the highest probability of occurrence at sizes of concern for structural integrity. It was required that 100% of such defects be detected. Lesser reliability was acceptable for defects with lower occurrence probabilities and for smaller defects. The sizes of the defects to be detected and sized were based on fracture mechanics calculations. A 'fitness-for-purpose' size was defined for each component based on the critical size but with a safety factor to provide a margin to the size which would have structural integrity significance. Acceptance standards for manufacturing inspections were set at smaller sizes to ensure components of the highest possible quality and 50% probability of detection was required for such defects. However, the inspections were assessed principally against the fitness-for-purpose sizes. For in-service inspections, only the latter were used.

As discussed above, it is necessary to specify all aspects of defects which influence the ability of ultrasonic inspection to detect and size them. To do this, the defect types which might occur at the fitness-for-purpose sizes must be identified. Once this has been done, their characteristics must be established to provide a defect specification for the design and assessment of the inspections. For Sizewell B, the defects which might occur during manufacture were determined from experience in manufacturing similar components and also from an understanding of the defect types which might result from the manufacturing processes involved. The defects were divided into four categories of likelihood at fitness-for-purpose sizes: 'likely', 'unlikely', 'highly unlikely' and 'inconceivable'. It was a requirement of the independent assessment process that inspections should be highly effective for 'likely' or 'unlikely' defects at fitness-for-purpose sizes. A lesser level of effectiveness was permissible for 'highly unlikely' or 'inconceivable' defects at fitness-for-purpose sizes and for 'likely' or 'unlikely' defects at manufacturing acceptance standard sizes. Experience of their occurrence and analysis of the mechanism through which they



Sizewell B dome *Courtesy British Energy Group plc*

would develop were used to determine the position, orientation and roughness of the defects identified above.

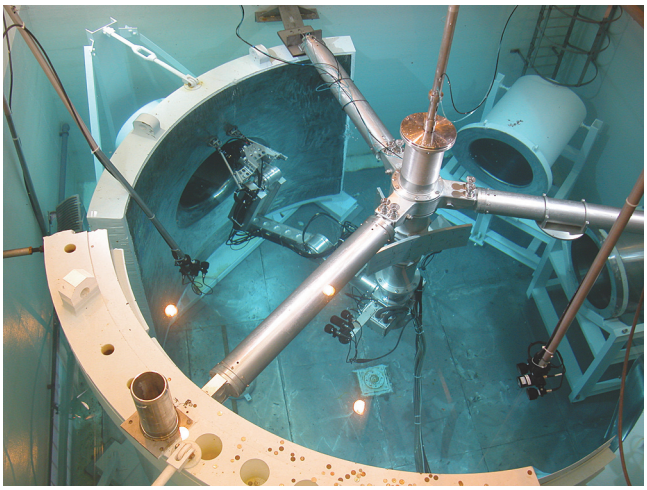
A similar approach was adopted for in-service inspection objectives, except that here it was experience of the occurrence of defects in service and analysis of in-service degradation mechanisms that were the basis of the defect specification.

2.2 The assessment process for the RPV (Validation)

The obvious way to assess an inspection is to apply it to a realistic test-piece containing artificially introduced defects. However, this simple approach has a number of major problems. Foremost among these is the difficulty of producing convincing evidence based on the relatively few defects that it is practicable to include in test-pieces. It can be shown statistically that, to establish 95% confidence in 95% probability of detection, 59 successful defect detections are needed for each defect type at a particular size. A single failure means that the trial must be extended so that 92 out of 93 defects are detected if the above levels of confidence and reliability are to be demonstrated. It is impracticable and highly expensive to produce defects in test-pieces in such numbers given the level of quality control needed to ensure confidence in the defect characteristics. Conversely, a single failure in a small population of defects is highly damning. Test-piece trials by themselves, therefore, usually have the capability to determine that an inspection is ineffective but lack the power to confirm high reliability.

The recognition of the above statistical difficulties led to a different approach for Sizewell B in which the use of test-pieces was combined with theoretical arguments and other available evidence. This involved assembling all relevant evidence for the effectiveness of an inspection. This includes:

- an analysis of beam angles to ensure that all possible defects are observed under as near specular conditions as possible;
- use of experimentally validated mathematical models of the inspection process to predict defect responses;
- experimental evidence resulting from use of similar inspections elsewhere, for example in exercises such as PISC;
- parametric studies of the effects of parameters such as cladding and anisotropic structures.



Validation for automated Sizewell B 10 year RPV inspection
Courtesy Serco Group plc

Such an assembly of theoretical and laboratory evidence is termed a technical justification (TJ). A particular focus of the TJ is identification of so-called 'worst-case' defects. These are the defects amongst those in the defect specification which are the most difficult from either a detection or a sizing standpoint. If it can be shown that the inspection is effective for the worst-case defects, then it can be argued that it will be at least as effective for all other defects in the specification. This has the potential to simplify the work needed to establish inspection effectiveness by allowing it to focus on a few chosen defects. The benefits of the TJ are that it allows the results of practical trials using specific defects to be generalised over the full range of permutations of important defect parameters possible in practice.

Even though both test-piece trials and technical justifications were involved for Sizewell B, the potential of the combined approach was not exploited fully. Test-pieces were designed independently of the TJ rather than utilising the information to enhance their effectiveness by ensuring the defect population included the worst-case defects. As a result of the Sizewell B pioneering work in this area, later qualifications under the ENIQ methodology integrated the two strands of qualification activity more completely. This is discussed further in Sections 4 and 5 below.

The test-pieces used for the Sizewell B work were very costly. Many of them are full-size replicas of real components – making them very heavy and expensive. Assiduous attention was paid to incorporating 'realistic' defects even though it was uncertain whether a hydrogen crack, for example, produced in the laboratory was necessarily representative, in ultrasonic terms, of a real crack. Incorporation of defects in small coupons into larger test-pieces is fraught with problems. All defects associated with the welding used to incorporate the defects must be avoided because their presence gives away the location and existence of the defects being sought. Even tiny slag or porosity are easily seen ultrasonically because they reflect isotropically.

Another feature of the Sizewell B validations was the way in which both procedure and personnel were qualified by the same test-piece inspections. If a failure occurs, it can be difficult to determine where the fault lies. This is an area where subsequent developments have shown an alternative way in which personnel and procedure/equipment qualification are separated. This has now been widely adopted as discussed further in Sections 4 and 5.

2.3 The assessment process for other IoF components

Although independent validation of inspections was required for all IoF components, the approach adopted varied for different groups of components. As discussed above, validation was at its most rigorous for the reactor pressure vessel. This reflected the central role of the RPV in reactor safety but also the political reality of the time where reports such as those of the Marshall Study Group and comments by eminent figures such as Sir Alan Cottrell focused on the RPV.

Validation of the ferritic IoF components other than the RPV did not require a TJ. The work was entirely practical. Lloyds qualified the personnel and a validated inspector was used to apply the procedure to test-pieces at the Inspection Validation Centre (IVC) in the UK. The latter process was used to validate the procedure.

The austenitic IoF components were validated by a unit within the plant owner's organisation, which was independent of those developing the inspections and training the personnel. The need for development work is acute for such components because of the uncertainties about the metallurgical structure of austenitic components and its effect on ultrasonic inspection. The materials used and the precise method of fabrication are critical and small variations can often produce profound changes in structure. This means that all such components must be treated as individual cases and some experimental work will always be needed in the qualification of their inspections. It will often be the case that development work will reveal that only a limited performance is possible. The figures produced by the work for detectable sizes etc can be used to set performance levels since there is little point in demanding more than is intrinsically possible, given the characteristics of the material.

Validation for in-process inspection of Sizewell B bottom dome
Courtesy Serco Group plc

3. ASME XI in-service inspection requirements

3.1 Introduction

A requirement was added to the ASME XI Code in 1991 that certain ultrasonic inspections must have their performance demonstrated prior to use for ISI. Previously, the code had specified the detail of the inspections themselves in terms of the probe angles to be used, sensitivity for scanning and recording data etc. This continues to be the case for those inspections not included within the scope of the performance demonstration requirements. However, for those inspections which are included, the only need is to demonstrate that they can meet certain performance targets. Appendix VIII contains a list of those parameters which must be specified in the inspection procedure but does not give the values that such parameters must assume.

The components whose ultrasonic inspections must be qualified are defined in Appendix I of the code. The list of components has increased steadily since 1991 as performance demonstrations have been developed for more and more inspections. At present, the requirements extend to the following[6]:

1. **Reactor Vessels exceeding 50 mm thickness**
   - Shell and Head Welds excluding Flange Welds
   - Nozzle to Vessel Welds
   - Nozzle Inner Radii
   - Clad/Base Metal Interface Regions
2. **Piping Welds**
   - Welds between wrought austenitic pipes
   - Welds between ferritic pipes
   - Welds between cast austenitic pipes (reported as 'in preparation' in the 2007 Edition of ASME XI)
   - Welds between pipes of dissimilar material
   - Overlaid welds between wrought austenitic pipes
3. **Bolts and Studs**

The performance demonstration requirements for the components identified above include the ultrasonic inspection procedure, the equipment used and the personnel applying the inspection. The requirements for the latter, including the prior qualifications, training and experience required, are set out in Appendix VII of ASME XI. Appendix VIII contains the performance demonstration requirements for the overall system of procedure, equipment and personnel.

The inspections for components not included in the above are given in ASME Section V or in Appendix III of ASME XI. Also, where the detailed arrangements for components subject to Appendix VIII requirements have not yet been completed, their inspection is required to be carried out as defined in Appendix I. Inspection of RPV stud flange threads can either be qualified by performance demonstration as defined in Appendix VIII, Supplement 8, or carried out as defined in Section V.

In addition to the qualification requirements found in Appendix VIII, a further set of requirements are given in Article 14 of ASME Section V. These are more extensive than those in Appendix VIII and resemble, in many ways, the requirements of the ENIQ methodology discussed in Section 4 below, although there are important differences. These surround the fact that practical trials are still used in an attempt to provide statistical confirmation of capability.

At present, Article 14 is not a standard requirement called up by other parts of the ASME Code as is Appendix VIII. To be used, it must be referenced by another part of the code or by a Code Case for a specific inspection. It is required, for example, by Code Case N-729-1 for the inspection of CRDM penetration welds in PWR upper heads[10]. Article 14 is discussed further in Section 5 below.

3.2 Performance demonstration as required by Appendix VIII

The requirements of Appendix VIII have developed steadily since its introduction in 1991 and a number of important changes have been made. The current version reviewed in this paper is that included in the 2007 edition of ASME XI. The Appendix starts by listing the essential variables whose value must be specified in the inspection procedure. This is to ensure that the procedure is comprehensive so that, when qualified, there are no unspecified variables which could cause the performance to vary from that established by qualification. The detailed requirements for performance demonstration of the components identified above in Section 3.1 are given in a number of Supplements to Appendix VIII as follows:

Piping Welds	Wrought Austenitic	Supplement 2
	Ferritic	Supplement 3
	Cast Austenitic	In Preparation
	Structural Weld Inlay Austenitic	In Preparation
	Dissimilar Metal	Supplement 10
	Overlay	Supplement 11
	Coordinated Implementation[1]	Supplement 12
	Coordinated Implementation[2]	Supplement 14
Vessels	Clad/Base Metal Interface	Supplement 4
	Nozzle Inspection from Outside	Supplement 5
	Reactor Vessel Welds	Supplement 6
	Nozzle Inspection from Inside	Supplement 7
Bolts and Studs		Supplement 8

[1]This Supplement covers joint qualification for Supplements 2 and 3.
[2]This Supplement covers joint qualification for Supplements 2, 3 and 10 for inside inspections.

Appendix VIII specifies the parameters which must be measured when substituting one set of equipment for another and the tolerances which must be met if an existing qualification is to remain valid. Supplement 1 defines methods of measurement.

3.3 Requirements of the supplements to Appendix VIII

Rather than deal exhaustively with the detail of each of the supplements, the discussion below focuses on the qualification of piping welds and that of reactor vessel welds other than cladding.

These components illustrate the principles of ASME XI, Appendix VIII performance demonstration and permit a discussion of the salient features of the general approach.

Each supplement starts with a set of requirements for the specimens used for performance demonstration and requires that the specimens shall be large enough so that reflections from the edges do not interfere with the signals from the defects within the blocks.

3.3.1 Pipe inspection qualification

Supplements 2 and 3 require the use of at least 4 specimens. The set must include specimens with a thickness of at least the maximum to be encountered in practice less 13 mm for wrought austenitic or 25 mm for ferritic welds. Others must have a thickness not greater than the minimum possible in practice plus 2.5 mm. The minimum and maximum pipe diameters must also be represented in the set. However, if the maximum outside diameter to which the inspection procedure is applicable exceeds 600 mm, there need be no specimen with a diameter exceeding this value. There is no requirement that the actual diameter and thickness combinations to be encountered in practice are represented in the set.

There is a requirement that any manufactured conditions affecting scanning such as un-ground crowns, or would produce interfering signals such as counterbores, are included in the specimen set. There is a further requirement that 50% of the flaws in the specimens are coincident with such conditions. There is, however, no requirement to ensure that defects are only coincident when this is relevant to the actual practical situations encountered.

All flaws included are required to be cracks, mechanical fatigue and either thermal fatigue or inter-granular stress corrosion cracking (IGSCC). At least 75% shall be of the latter types for wrought austenitic materials. For ferritic materials, 75% of the flaws shall be mechanical or thermal fatigue cracks. There are no stipulations regarding flaw orientation other than a requirement that at least one and a maximum of 10% of them shall be oriented axially to the pipe. No permissible ranges for tilt or skew are given.

There is no requirement in Appendix VIII that austenitic test specimens are made using the same welding procedure as the site welds. There is, therefore, an implicit assumption that austenitic weld procedures do not influence the weld structure in a way which affects ultrasonic inspection.

So far as flaw sizes are concerned, for detection assessment at least $^1/_3$ should have a through-thickness extent (TTE) greater than 30% pipe wall thickness and a minimum of $^1/_3$ should have TTE between 5% and 30% wall thickness. No length requirements are given. For assessment of depth sizing, a minimum of 20% of the flaws used shall be in each of the three TTE ranges: 5%-30%; 31%-60%; 61%-100% wall thickness.

The criterion for success in detection when assessing personnel is that a certain number of flaws must be detected from those included in the specimens presented. A minimum of 5 flaws must be used and all five must be detected for success. If 7 flaws are used, 1 failure is permissible. For 9 flaws, 2 failures are allowed and so on. It is noteworthy that there is no stipulation about which flaws in the set it is permissible to overlook. For example, it would be possible to fail to detect the two largest flaws in a sample set of 9 flaws and still be judged successful. There is also no requirement to include the flaws that are the hardest to detect and size.

In addition to success in detecting flaws, it is also necessary that the inspector under assessment does not report too many false calls from areas of the component where no defects exist. It would be easy for inspectors to detect all the defects by increasing the sensitivity if very large numbers of false calls were permissible and it is clearly necessary to place limits on these. Each specimen is divided into grading units, each including at least 75 mm of weld length. These are described as flawed or unflawed according to whether they contain a defect. Two times as many unflawed as flawed grading units must be used in detection assessment and similar criteria apply to the permissible number of false calls as to detected flaws. The minimum of unflawed grading units is 10 and there must be no false calls at this number. When there are 12 grading units, one false call is permissible and so on.

For flaw sizing, the RMS error in the reported values must not exceed 19 mm for length measurement and 3 mm for TTE measurement.

For qualification of personnel, grading unit numbers are selected as discussed above and the number of failures to detect and false calls in relation to numbers of flawed and unflawed grading units respectively determine whether a candidate has passed. Qualification of inspection procedures is done using the equivalent of three personnel qualification sets. To qualify the procedure, detectability of all flaws within its scope must be demonstrated. No guidance is given on how this might be achieved. Successful personnel performance demonstrations can be combined. Presumably each defect must have been detected by at least one inspector to establish detectability because some failures are permissible even in a successful personnel qualification. However, this is not stated explicitly. Moreover, there is no criterion for the margin of detection. A situation in which a flaw was only detected by one inspector with a small margin of signal-to-noise or signal-to-recording-level ratio would not indicate that the procedure is a reliable one for that defect. Furthermore, the absence of a requirement to include worst-case defects as noted above means that the outcome of the assessment may be too optimistic.

Another area of uncertainty is what the scope of the inspection procedure actually is in terms of flaw types. This is because the list of requirements for the procedure in paragraph VIII-2100 does not include any need to define scope in terms of defect types.

3.3.2 RPV weld inspection qualification

The requirements for performance demonstration of reactor vessel welds other than the clad/base metal interface are given in Supplement 6 of Appendix VIII.

There is a requirement that the total specimen set offers at least 1m^2 of scan surface. It should also include at least one block with a thickness of 90% at least of the maximum thickness to be inspected.

The requirements for the positions and TTEs of the flaws in the specimens is as given in the table below. No requirements are given for flaw lengths.

Defect Location	Defect TTE (mm)				
	1.9 – 5.1	5.1 – 8.9	8.9 – 14	14 – 19	19 – 50
Inner 10%	X	X	S	S	-
Outer 10%	X	X	S	S	-
11 – 30%T	-	-	X	X	S
31 – 60%T	-	-	X	X	S
61 – 89%T	-	-	X	X	S

X applies to detection and sizing flaws; S applies only to sizing flaws; T is the thickness of the thickest specimen in the specimen set

The specimen set should contain at least one of the flaws included in the above table in each of the TTE and depth ranges.

At least 55% of the flaws are required to be cracks of unspecified type. The balance can be cracks or fabrication flaws such as slag or lack of fusion. Flaw orientation is not specified other than a requirement for the flaws to be aligned within 10° of either the parallel or perpendicular to the clad direction. At least 40% of the flaws shall be in each category for procedure qualification and 20% for personnel qualification.

There is a requirement to select flaws from the above table so that both the maximum and minimum metal path ranges are included as well as a representative range of sizes and locations.

For procedure qualification, the detection set should include the equivalent of three personnel qualification sets. The number of flaws in the latter are selected from a table given in the appendix. The minimum number of flaws is 7 and no failures are permissible at this number. When 12 flaws are used, one failure is permissible and, at 16 flaws, 2 failures are allowed. As for the piping supplements, it is not specified who decides on the number of flaws to be used, though it could be assumed that this will be the qualification body so that the number is kept secret. Following on from this, it is also unclear how many flaws should be included in a personnel qualification set. The requirement that such a set include three personnel sets doesn't fix the number since the number of flaws in a personnel set is flexible.

The number of false calls allowed is a/10 where a is the total scan area in the specimens used measured in square feet. RMS TTE sizing errors should be less than 6 mm and RMS Length error less than 19 mm.

As for piping, procedure qualification is required to demonstrate detectability for all flaws within the scope of the inspection procedure. The same caveats apply as for piping (see above).

3.4 Discussion of Appendix VIII

As mentioned earlier, much of what is contained in Appendix VIII arises from the need to provide a pragmatic approach for qualifying inspections carried out on about 100 reactors of widely different types and designs. The inspections involved are all in-service inspections aiming to detect the defect types which might arise in plant operation. Nevertheless, the requirements of Appendix VIII could be looked at in terms of whether they provide a basis for qualification of manufacturing inspections since only the defect types will differ.

The major problems with Appendix VIII arise from the need for it to be general. In attempting to cover such a wide range of plant, it inevitably leaves issues undefined which are crucial in determining inspection performance and which must be specified if inspection qualification is to provide the necessary confidence in the inspection. These are as follows:

- There is no requirement to identify the defects which are the subject of the inspection. The same test-pieces are used regardless. In some cases, specific defect types such as IGSCC or thermal fatigue are mentioned but, in general, there is no requirement to identify which particular defects are the appropriate ones. The exception is that, when the inspection is designed to detect IGSCC, at least 4 field-removed IGSCC flaws shall be used.
- The absence of a requirement to define the defect types which form the object of the inspection is puzzling because inspection procedure qualification in Appendix VIII must determine detectability for the flaws 'within the scope of the procedure'.
- Flaw orientation is a crucial parameter in determining the ultrasonic beam angles which are appropriate for a particular inspection. An inspection which might be highly effective for flaws in one set of orientations could be far less effective for another set. Thus, qualification must be carried out using a set of flaws with the same orientations as those to be expected in the flaws which are the subject of the inspection procedure. In spite of this, Appendix VIII contains no specification of flaw orientations other than one relating to whether the flaws are generally parallel or perpendicular to a particular direction such as a pipe axis or cladding direction. This limits severely the value of any qualification carried out using Appendix VIII. It seems to be implied that either the real flaws would necessarily have the same orientation as the ones in the test specimens or that orientation is unimportant in determining ultrasonic performance. Both these are unjustifiable assumptions.
- There is a requirement in Supplement 5 relating to nozzle examination from the outside to establish the maximum possible misorientation between the beam and the defect using modelling. The test-pieces used must then include such a misorientation. However, it is difficult to know how misorientations are established since there is no requirement to define the defect orientations which are the subject of the inspection or even to determine those in the test-pieces.
- The structure of austenitic welds is a key parameter in determining their inspectability. The structure, in turn, is determined by the welding procedure and materials used. In recognition of this, it is common to require that test specimens be made using the same welding procedure as that used on the actual plant. There is no such requirement in Appendix VIII, possibly because it would be a very onerous requirement given the large number of procedures used on American plant or because, for many reactors, the welding procedures used are unknown.
- The specimen sets used under Appendix VIII all contain a wide range of sizes. It could be argued that the purpose of qualification is to provide confidence in the ability of an inspection to detect and size defects of concern for structural integrity. From this, it follows that the defects used should be concentrated around a size derived from structural integrity considerations. A few larger or smaller defects might be included to provide information on inspection performance at other sizes, but the main concern is to show that the inspection can identify defects which might threaten plant integrity. By prescribing such a broad spread of sizes, Appendix VIII dilutes the confidence that the inspection can achieve such an objective. Indeed, there is no requirement in Appendix VIII to determine a size of structural significance and focus qualification on this size. This weakness again probably stems from the very wide range of plant involved and the logistical difficulty of carrying out any kind of individual assessment.
- For piping, the thickness-to-diameter ratio can be important in determining inspectability and the appropriate beam angles to use. However, while Appendix VIII specifies the use of maximum and minimum diameters and thicknesses, it doesn't require that the exact geometry be used in test specimens *ie* the most difficult thickness-to-diameter ratio encountered in practice. This, again, is probably a result of logistical difficulties but could result in the qualification being undermined if it doesn't include the most difficult geometry.

In addition to the points made above, it should also be borne in mind that the number of defects involved is quite low for any demonstration of high reliability with high confidence. For personnel qualification, a minimum of between 5 and 10 flaws is specified depending on the component in question. For piping and RPV weld inspection, three personnel sets are needed for procedure qualification so the number of flaws involved would be a minimum of between 15 and 30. For nozzles, a minimum of 10 flaws is specified for procedure qualification. These numbers are too low to establish statistically any reasonable level of confidence in high reliability. This would be true even if the flaws were all of the same size and type so that they form part of the same statistical population. However, as discussed above they are distributed over a range of sizes and have unspecified (and hence uncontrolled) orientations. Moreover, there is no requirement that the flaw population includes the defects that are hardest to detect and size. Consequently, the statistical significance of the performance demonstration is even more limited. For personnel qualification, a number of failures are permissible, depending on the number of defects used. In such small sample sizes, any failures mean that confidence in high reliability is extremely low, particularly if the failures relate to the larger defects in the set. These are the reasons why the approach adopted for the Sizewell B RPV involved the use of theoretical evidence in the form of a technical justification in addition to the practical trials as discussed in Section 2 above. There is some mention of the

use of theoretical modelling in Supplement 5 (nozzle examination from the outside surface) and in Non-Mandatory Appendix M to ASME XI (validation criteria for models). However, modelling here is used only to extend qualifications to new geometries or to demonstrate the equivalence of test-piece and real component geometry. It does not form part of the body of evidence used to demonstrate performance in the first instance.

The conclusion from the discussion above is, therefore, that performance demonstration as described in Appendix VIII cannot produce high levels of confidence in high reliability of inspection for defects of structural significance for four general reasons:

1. The demonstration relies solely on experimental measurements on test-pieces. The limited number of defects and their spread of sizes and positions mean that the results can have no statistical significance.
2. Key parameters of the test-pieces such as their geometry, weld structure, defect types and defect orientations are not specified and controlled. This means that the relevance of the demonstration to any particular inspection is uncertain.
3. There is no requirement in Appendix VIII to determine the sizes which are significant for structural integrity. The defects are required to cover a range of sizes and so very few are concentrated at the size of potentially greatest interest.
4. There is no requirement to include the defects which are most difficult for the inspection to handle in the test-pieces. They could therefore give an optimistic view of inspection capability.

4. European developments

4.1 Background

In the early 1990s the European nuclear utilities were considering how to approach the issue of validation/performance demonstration. As mentioned earlier, the PISC programme had revealed significant shortcomings in the code-based approach to producing inspection procedures. From this followed a need for independent assessment of inspections to ensure they are capable of detecting and sizing the defects of concern for structural integrity in situations where the consequences of failure are intolerable.

The Joint Research Centre (JRC) of the European Commission had been the Operating Agent for the PISC programmes, providing the administrative support to the various committees who organised the projects. The committees themselves involved members from European nuclear utilities, research and development organisations and inspection vendors. The PISC programmes had reached a conclusion and the JRC took the initiative to establish a new committee to build on their results and develop a European system for inspection assessment involving the same range of organisations that had been involved in PISC.

The committee was not in favour of adopting either the Sizewell B or the ASME XI, Appendix VIII approaches. Appendix VIII was dismissed for a number of reasons. Firstly, it was judged to be technically inadequate for the reasons discussed in Section 3 above. Secondly, the approach was based solely on the use of test-pieces and, unless the American facilities were used or the test-pieces were drawn from a central pool, would be very expensive to implement on a country by country basis. Agreement amongst the different European countries on the technical requirements for a central pool of specimens and on their use across national frontiers was seen as a step too far at that time. Finally, the ASME XI approach is very prescriptive and so not very responsive to the different technical requirements of different plant as well as to the different regulatory requirements which apply in different countries. For all these reasons, there was strong opposition to the adoption of ASME XI, Appendix VIII or to anything resembling it.

The Sizewell B RPV validation approach was seen as more promising but overly dependent on the use of big test-pieces. It was felt that theoretical evidence had not been used as strongly as it might to reduce the demands on test-piece use. It was also felt to be necessary to have a European approach which was not prescriptive regarding the detail of inspection assessment but rather set out the principles which should apply. In this way a common European approach could be developed while leaving individual countries to determine the detail of how to implement the approach based on their own technical and regulatory requirements. At that time, the IVC in the UK was producing a draft British Standard on validation of inspections based on its own experience with the Sizewell B inspections and this was adopted as a starting point for the discussions of the new European Committee.

The term adopted for the process of independent inspection assessment was ‘inspection qualification’ and the new committee was called the European Network for Inspection Qualification (ENIQ). The first task of ENIQ was to produce the European Methodology for Qualification of Non-Destructive Testing (EMQ), which is now in its third issue[7]. Changes from the first and second issues are largely ones of clarification and re-phrasing. The essential principles, which are discussed below, have remained unchanged.

The executive responsibility within ENIQ rests with the Steering Committee. This has representatives from all the European nuclear utilities as voting members. All other attendees are at the invitation of the national voting member. ENIQ is supported by two task groups, one on qualification and the other on risk-informed ISI. These are where the working documents for Steering Committee approval are produced. Administrative support is provided by the ENIQ operating agent which is the Institute for Energy at the JRC, Petten.

4.2 The European Methodology for Qualification of Non-Destructive Testing

Although the EMQ was developed in the context of ISI, as its Scope points out it is equally applicable to the qualification of manufacturing inspections and to that of non-nuclear inspections.

The EMQ document identifies the roles and responsibilities of the different parties in inspection qualification. Specifically, it identifies the need for a qualification body (QB) which is set up in such a way that it is independent of commercial and operational pressures. Three types of QB are possible[8]:

- ❑ Type 1 – An independent third party organisation.
- ❑ Type 2 – Part of a utility organisation set up on a long-term basis.
- ❑ Type 3 – An ad-hoc body set up for a particular inspection.

A basic requirement of the EMQ is that the objectives of the qualification and all related information should be available at the outset. This includes the following:

- ❑ Component geometry and dimensions.
- ❑ Component materials and fabrication method.
- ❑ Defect sizes at which high probability of detection is required.
- ❑ Required sizing and positioning accuracy.
- ❑ Defect types, positions, orientations and surface morphology.

This means that the qualification is being directed at a specific inspection. The qualification process here is not a generic one like that in Appendix VIII. Consequently, it takes into account all the salient features of the inspection and so is valid only for that particular inspection. The information above is that which ideally would be taken into account when an inspection is designed. In reality, inspections are sometimes designed before all the information is available. In that situation, subsequent qualification often identifies inadequacies in the inspection which must be remedied before it is used. Qualifying prior to use ensures that there is confidence in the procedure but sometimes, programme pressures require inspections to be carried out earlier. In that situation, the inspection is at the risk of the plant owner or inspection vendor since subsequent qualification may reveal that the inspection was inadequate to an extent that requires re-inspection with a modified procedure.

A fundamental aspect of the EMQ is that qualification is a combination of practical trials and technical justification (TJ). The methodology recognises the great difficulty of qualifying an inspection on the basis of practical trials alone for the reasons discussed earlier in this paper. The precise content of the TJ depends on the particular inspection and what information is available. However, there will usually be a section containing an identification of the essential parameters for that inspection. This will be followed by a section known as 'Physical Reasoning' which explains in qualitative terms how the inspection was designed. The basis of the choice of beam angles, for example, in terms of the component geometry and the defect orientations of interest will normally be given. Other inspection parameters such as sensitivity, scanning pattern and sizing method could also be discussed in this section. If the inspection is amenable to prediction by mathematical modelling, one of the various models which have been validated by comparison with experimental data could be used to demonstrate quantitatively the adequacy of the sensitivity/beam angles chosen. Data from similar inspections or trials could also be included if it exists. Some features of the inspection may be difficult or costly to predict theoretically or to include in practical trials. These could be the subject of small-scale experimental or theoretical studies to determine their effect on the inspection. The results of such parametric studies can then be superimposed either on the predictions of the TJ or on the results of practical trials. In essence, the TJ is tailor-made to the particular inspection depending on what is available and/or necessary. A series of ENIQ Recommended Practices gives guidance on a range of issues including essential parameters analysis and the production of technical justifications.

A scientific justification of the inspection as contained in the TJ is the centrepiece of the ENIQ system of qualification. The need for practical trials is identified in the TJ if the evidence points in that direction. The nature of the trials which are appropriate is also determined in the TJ. The trials are, therefore, seen as providing supporting and complementary evidence rather than being the essence of the qualification as they are in the Appendix VIII approach.

The EMQ recommends that procedure/equipment qualification is carried out separately from that of personnel qualification through the use of open trials, if these are judged necessary to supplement the TJ. Open trials are ones in which information about the defects in the test-pieces used is known to those applying the inspection. The objective is to generate information which supports the ability of the inspection procedure and equipment to achieve the required performance. This is documented and submitted to the QB for their assessment of whether it makes the case, together with the TJ, that the procedure/equipment have adequate performance.

Personnel qualification is then carried out separately using blind trials in which all details of the defects involved except those normally available, for example expected locations and types, are unknown to the inspectors under assessment. Manual inspection will involve the direct inspection of test-pieces. Automated inspection may involve providing data assessors with print-outs which they must then interpret correctly. The essential feature is to qualify the inspectors' ability to use equipment/procedures which have already been shown to have adequate performance to achieve the required results. In this way, the difficulties sometimes encountered in knowing which of three factors of unknown capability (procedure, equipment, personnel) are responsible for failures in qualification are avoided. The inspection procedure requires the use of personnel with existing NDT certification to some national scheme (in the UK these would normally be either PCN or ASNT). The TJ may be able to make the case that the skills demonstrated in this way are sufficient for application of the particular inspection. This will then need assessment by the QB. Usually, however, additional trials will be needed because there are novel features which present challenges which are not assessed by the national scheme.

So far as practical trials are concerned, it is recognised that test-pieces replicating the component in question containing accurately simulated defects are not the only types that can be used. Simpler test-pieces are possible if theoretical arguments can be used to relate the results obtained to those which would have been obtained from the real situation.

The qualification process to be adopted for a particular inspection is determined by the QB who produce a written qualification procedure describing the steps to be carried out. It is sometimes only possible to complete this once the TJ is available and the extent of any practical trials which are needed is apparent. After the qualification, the QB assemble all relevant information into a qualification dossier which is available for external scrutiny. This includes the objectives of the inspection, the inspection procedure, the TJ, the qualification procedure and a report indicating the basis on which the QB has awarded (or refused) qualification.

Following publication of the EMQ, the IAEA has taken the initiative to propose a methodology for VVER plant in Eastern Europe[9]. The system for qualification in the IAEA document is virtually identical to that in the EMQ. The only differences are in the responsibility for activities such as production of a qualification procedure. In the EMQ this rests with the QB. In the IAEA document it is with the utility but the QB would need to approve it.

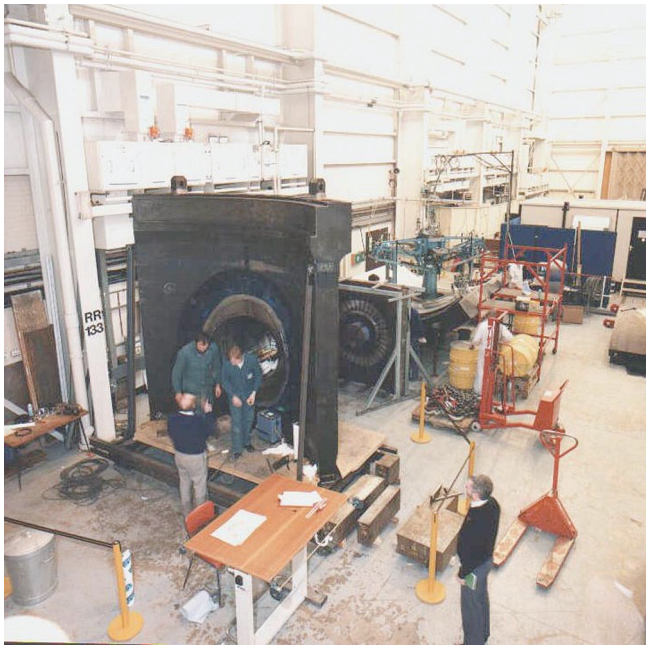
5. Discussion

As discussed above, there are two distinct approaches to inspection qualification which have been adopted so far. These have been designated generic and specific qualification. The approach in ASME XI, Appendix VIII is generic qualification. It is not specific to any particular plant or, in general, to any specific defect type. The one exception is that, where IGSCC has occurred, there is a requirement to include this defect type amongst the ones in the test-pieces. Otherwise, flaw types are specified as mechanical fatigue, thermal fatigue, cracks of unspecified type, machined notches or manufacturing flaws such as slag or lack of fusion depending on the particular supplement applicable. There is no requirement in this situation that the crack types used are relevant to the particular component. Furthermore, the crack orientations are not specified and the sizes are distributed over a wide range. In essence, the qualification obtained though Appendix VIII is valid only for the test-pieces and defects used to carry out the practical trials. The relevance of these to a particular inspection of a particular component may not be easy to establish considering the lack of prescription of key defect and component parameters.

A further point is that Appendix VIII, with one exception, specifies only practical trials as a means of conducting qualification. Modelling is mentioned in Supplement 5 on outside surface inspection of nozzles. Here, because of the complex three-dimensional geometry, the model is of the type that can be used to assess the misorientation angles between the beams used and the flaws in the test-pieces. It is then used to show that, on the real component, the misorientation angles would be the same or smaller. The models are not used to predict responses but simply to show that the angles of incidence obtained in test-piece trials would be obtained on the real component, taking account of any differences in geometry or size. The proof of inspection performance still comes from the test-piece results. This reliance on test-pieces imposes severe restrictions on the confidence in high reliability that can be produced by the qualification. The only evidence relates to the test-pieces and the defects they contain. There is no demonstration that the same results would have been obtained over all the permutations of essential defect variables possible in practice. Indeed there is no requirement to even set these variables out as objectives for both the inspection itself and its qualification. The numbers of defects, particularly since they are distributed over a range of sizes and positions, have no statistical significance.

Appendix VIII represents a pragmatic approach to the problem of qualifying a large number of inspections on plant of widely differing designs. It could not be used to generate confidence in a particular inspection of a particular plant component. So far, Appendix VIII has been used in the USA, some European countries where there is a legal requirement to use the applicable codes in the country of origin of the reactor and, in a slightly modified form, to certain Japanese inspections.

The ENIQ methodology represents the most widely used approach of specific qualification. Here there is a requirement to state at the outset the objectives of the inspection. All key input parameters relating to the component, the defects and the required performance must be stated. These provide design criteria for the inspection and also the basis of its qualification. The qualification that is developed is, therefore, very specific to the particular inspection. The system makes provision for the extension of the qualification to components of slightly different geometry, to new defect types or parameters or to substitutions of equipment. These would be achieved either theoretically or through limited experimental trials as appropriate.



Inspection Validation Centre test hall during Sizewell B validations *Courtesy Serco Group plc*

There is no intent to produce statistically significant sample sizes. Rather, the TJ is used to identify the values of the permissible defect parameters which would pose the greatest problems for the inspection. Practical trials are then focused on such defects, usually at the size of concern for structural integrity. The intent is to provide evidence that margins of detection, sizing accuracy etc will always be sufficient to give confidence in the performance of the inspection.

A further feature of the EMQ compared to Appendix VIII is the way that personnel qualification is separated from that of the equipment and procedure. In Appendix VIII, procedure qualification is arrived at via personnel qualification. The rules in Appendix VIII about how this is done are not clear but when a failure in personnel qualification occurs it cannot be clear whether this has arisen from a fault in the procedure or equipment. Having the latter qualified first, as required by the EMQ, makes it obvious when the problem is with the particular inspector under assessment.

Article 14 of ASME V identifies 3 levels of rigour for qualification. These differ essentially in the number of test-piece trials carried out. No trials are needed for low rigour qualifications, only a TJ. At high rigour, enough test-pieces are needed to produce high confidence in high reliability even though the number needed would be impracticably large. ENIQ has also considered the issue of qualification rigour but rather than specify how this should be implemented, it has provided guidelines[11] on the factors to consider. The objective is to provide a level of confidence appropriate to the safety significance of the component in question and to the role played by inspection in assuring safety.

The other important input in determining the appropriate qualification approach in the ENIQ approach is the complexity of the inspection. The question of whether and what type of practical trials are needed in qualification is very dependent on the particular circumstances of the inspection. The following factors are the ones which determine this:

- Geometry and thickness of the component – parallel-sided components less than about 75 mm in thickness are simpler than, say, nozzle to shell welds in shells around 200 mm in thickness.
- Component material – ferritic or austenitic.
- Characteristics of the defects which must be found and sized – size, position, orientation, surface topography. Smooth defects oriented such that beams can be directed to achieve specular reflection and exceeding 10 mm in through-thickness extent should be easy to detect. Smaller, rough defects in difficult orientations, for example crotch corner defects, would be more demanding.
- Required accuracy of sizing.

If the inspection is a simple one, imposing no unusual demands, it may be that the qualification of the procedure can be achieved through the use of a Technical Justification alone. Any difficult features such as cladding could be handled through specific parametric studies of their effect in small laboratory experiments. So far as personnel are concerned, there will be prerequisites relating to experience and the possession of a suitable certificate awarded by a national certification scheme meeting the requirements of a recognised international standard such as EN 473, ISO 9712 or ASNT. If the TJ can argue that obtaining such a certificate has required the inspector to demonstrate his competence under similar circumstances to those he will face in the particular examination, it may be possible that no or limited further assessment is needed. If further assessment is judged to be needed, it may be that this can be done with simple test-pieces designed to examine the points of difference between the particular inspection and the run of the mill.

For automated inspections, the roles of data collector and data interpreter are usually separated. Again, independent schemes exist to train and qualify personnel in the use of the different aspects of automated inspections and these may prove to be sufficient or largely so.

At the other extreme, a highly complex inspection imposing novel or severe demands on both the procedure and personnel will require full qualification involving realistic test-pieces.

The decision on what form of qualification is appropriate and what types of test-pieces are needed must be taken case by case. Expert judgement is needed and, while the plant owner may make proposals and produce a TJ to support them, the decision must ultimately be taken by an independent body with the necessary technical expertise.

The major problems with the ENIQ approach are the high demands it makes on very scarce resources. The production of TJs requires personnel with a fundamental understanding of the physics of ultrasonic inspection. It also requires considerable experience in the subject so that the practical realities are also considered. Similar skills are also required in the personnel of the qualification body. There are many countries operating nuclear plant, especially in Eastern Europe, where the resources simply do not exist within the country itself. In such cases, external support is

needed at present. However, the use of the ENIQ methodology is stimulating development wherever it is used. ENIQ itself provides support through a range of Recommended Practice documents and difficult requirements such as mathematical models are now becoming commercially available. One of the ENIQ Recommended Practices[8] sets out the requirements for qualification bodies. This should provide guidance on the establishment of such bodies and also a basis for their independent audit.

The ENIQ methodology has been adopted throughout Europe and most countries operating nuclear plant have either set up a national qualification body or have turned to other countries for support in setting up ad-hoc QBs for carrying out specific qualifications.

General Conclusion

ASME XI, Appendix VIII has little technical merit and does not provide confidence in the ability of a specific inspection to meet particular targets. Its attributes are generality, low cost and simplicity.

The benefits of the ENIQ methodology are its flexibility and the requirement that it be developed taking into account the parameters of importance for a particular inspection. This means that it can provide confidence that an inspection can meet its objectives. Its major disadvantage is the requirement for scarce personnel skilled in the physics and practice of inspection to develop and implement qualification requirements.

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