Experience with Code Cases

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Biography
John Lilley has been engaged in the NDT industry since 1975, and has held certification to ASNT Level 3 since 1984. He has been instrumental in the application of TOFD and other automated ultrasonic inspection technology to industrial applications since 1988. He has written numerous technical publications and has been a regular contributor to codes and standards over the years. He is currently the General Manager of Sonomatic Ltd, and became a Chartered Engineer in 2007.

Background
Code Case 2235 was originally issued by the American Society for Mechanical Engineering (ASME) Boiler and Pressure Vessel Code (B&PVC) committee in 1996 [Ref 1]. The enquiry asked “Under what conditions and limitations may an ultrasonic examination be used in lieu of radiography, when radiography is required....”, and the code case text goes on to define these conditions and limitations. It essentially addresses the following:

i. Material thickness ranges and volumetric coverage requirements.

ii. The requirement for a documented examination strategy.

iii. The requirement for the examination to be carried out in accordance with Section V, Article 4 [Ref 2].

iv. The requirement for acceptable demonstration of performance of equipment, procedures and personnel on a qualification block(s).

v. Acceptance criteria based on a combination of flaw height and length measurements which are derived from a linear elastic fracture mechanics procedure.

vi. The requirement for automatic computer based data acquisition with data recorded in unprocessed form.

vii. Investigation and analysis criteria.

viii. Discrimination between surface and sub-surface flaws.

ix. Rules defining interaction in the case of multiple flaws.

Other factors are also addressed, but the above list describes the key elements of the initial code case. There has been extensive discussion through a variety of forums, and the document was revised nine times before being incorporated into the main body of Section VIII in 2008 [Ref 3]. The various revisions have addressed specific refinements although the fundamental document has remained relatively unchanged throughout this process. Along the way, essentially the same code case, with some modification, has been incorporated into the ASME Gas Process Piping Code B31.3 [Ref 4], in the form of Code Case 181, which was issued in January 2007. The generic term ‘Code
Case’ is used throughout this paper to refer to the use of UT in lieu of RT as described in Section VIII of the boiler and pressure vessel code, or in B31.3 Code Case 181. In both cases, fracture-mechanics-based acceptance criteria may be used in lieu of good workmanship criteria.

It is important to note that the key difference between conventional and code-case acceptance criteria is that the former is based on ‘good workmanship’ criteria, and the latter is supported by fracture mechanics calculation. A definition is offered here based on personal experience and interactions with clients, colleagues and partners over a period in excess of thirty year’s involvement with relevant projects, standard committees, R&D forums, seminars, workshops, conferences and legal work.

Construction codes and standards are intended to ensure that pressure equipment and structures are designed, fabricated and tested to consistent quality standards in the interests of safety and reliability. The early codes stipulated radiographic testing for the detection of flaws within the weld volume. Radiographic testing is however, inefficient for the detection of planar flaws, which must be a) preferentially aligned to the radiographic beam and b) with a gape that exceeds the applicable radiographic geometric un-sharpness value. Radiography is efficient however, for the detection of volumetric flaws such as slag entrapment, porosity, undercut, and poor weld profile [Ref 5]. It will also detect certain gross planar flaws, especially where these are associated with other types of volumetric flaw. All of the described volumetric flaws/conditions are indicative of poor workmanship and the codes provide very clear limits on what can be defined as unacceptable in terms of quality standards. Rejection levels are not derived from what is considered to be detrimental to the equipment once placed into service, but what is considered to be poor practice in terms of fabrication quality. This quality culture pervades throughout the entire fabrication process in much the same way as a strong safety culture leads to fewer accidents overall. The inference is that if welding procedures are applied diligently and good workmanship principles are upheld, then it follows that the occurrence of cracking and lack of fusion flaws is likely to be minimised. This process has been observed to be effective in that the incidence of boiler/pressure vessel failures has dramatically decreased following the introduction of codes. Attention to detail in construction NDT spills over to control and care of welding consumables, welding procedures, heat treatment, documentation, etc. It is a fundamental aspect of quality control (QC). There is also a psychological influence in that welders justifiably take pride in their work and are inclined to be averse to the stigma of being classified as ‘poor workmen’ through generating unacceptable levels of repair.

Construction ‘good workmanship’ NDT does not need to have a high Probability Of Detection (POD) because individual flaws which may go undetected are not likely to be detrimental to the use of the equipment in service. This is due to the high level of conservatism embodied within the good workmanship approach. The ‘good workmanship’ acceptance criteria of Section VIII Div 2 Part 7 (2008 Addenda) includes, but is not restricted to, the following:

- Cracks and lack of fusion/penetration – Not permitted
- Volumetric flaws – Limitations dependent on wall thickness

As an example, in the case of a pressure vessel with a wall thickness of 50mm, a 20mm long slag line would be rejectable to these criteria. The slag line may be less than 2mm in cross-section and would be expected to be rounded in profile. According to the code cases, a sub-surface, 39mm long by
4mm high, vertically oriented planar crack in a component of the same wall thickness would be permitted. The difference is that the good workmanship criteria are designed to maintain quality standards, thereby implying fitness-for-service, whereas fracture-mechanics-based acceptance criteria are designed to eliminate flaws exceeding given dimensions. The performance criteria for the NDT associated with these two approaches are very different. Good workmanship NDT may be less than perfect because it is designed to flag up when the fabrication process is going out of control by picking up systematic flaws (as opposed to detecting all flaws) which are indicative of underlying breakdowns in quality processes. There is less room for manoeuvre with fracture-mechanics-based acceptance criteria, hence the additional requirement for qualification.

Adoption of the code cases has steadily increased over the years to the point where in certain circumstances, radiographic testing of pressure vessels under construction has fallen away altogether. This process however, has occurred at a time when the industry has gone through:

- a) a period of changing regulatory influence (less influence from certifying authorities and insurers),
- b) increased dependency on formal quality processes and
- c) increased pressure on efficiencies of procurement.

These factors in combination have created the environment where it has become prevalent for fabricators and/or inspection service companies to interpret and apply the code cases according to their own understanding. This has been observed to have occurred without guidance or experience of working with codes in general, and by people whose native tongue is not English. The situation is not helped by the fact that the Code Cases have not been very well written or presented. In the author’s experience, this has led to situations where any ambiguities of interpretation tend to swing markedly towards the interests of the fabricator and/or inspector, often to the detriment of the end-client or purchaser of the plant requiring inspection. The consequential effects of this can be very costly in the longer term due to project delays, remediation cost and other project risks. It is suggested that the situation could be improved through stricter control, both in terms of initial specification of the procurement of NDT processes, but also tighter control throughout the fabrication process. The costs associated with quality assurance are very small compared to the project risk involved.

**The potential benefits of Ultrasonic Testing (UT) in Lieu of Radiographic Testing (RT) for production welding**

There are certain potential advantages of UT in lieu of RT during the fabrication process. Here is an overview of the more immediate benefits [see also Ref 6]:

- i. No radiation hazard – personnel can work in and around the inspection area
- ii. No requirement to transport pressure vessels/pipe spools to radiographic compounds
- iii. Speed. The inspection is completed in a shorter timeframe
- iv. Potential for improved quality of welding. If applied at the front-end of a project, it can be used at the weld procedure and welder qualification stage to optimise the welding process, hence minimising the likelihood of repair. See Figure 1.
v. Depth & positioning information provided. Unlike RT, precise repair co-ordinates can be provided, minimising the possibility of re-repairs through missed flaws

Other, less obvious benefits include:

i. The data forms a fingerprint for comparison with future in-service inspection data.

ii. The acceptance criteria of the code cases are in many cases more forgiving in terms of acceptable flaw size. This also reduces the repair frequency, and is especially the case for volumetric welding flaws.

Figure 1. Example of TOFD data taken from a B31.3 CC181 project. The indications scattered throughout the weld body were termed by the welders as ‘fish-eyes’. These are small lack of fusion flaws that form at the weld bevel faces as the welding head weaves across the weld body. They are a form of combined lack of inter-run and side-wall fusion that can be aligned in the axial direction, but also could potentially extend vertically by linking between weld passes. By adjusting the well time at each end of the ‘weave’, this flaw type (which was not detectable radiographically) was eliminated. Note also the interesting ID fit-up and stop-start interruption in the weld root penetration – all useful feedback for the design and welding engineers!

Taken in combination, the benefits in terms of project cost, quality, duration and risk can be very significant indeed. There have been cases where 24-hour working (as opposed to fabrication during the day and RT at night) enabled project durations to be halved, but conversely, where UT used in
lieu of RT has been impacted by lack of planning and oversight, delays and costs have been seen to escalate massively, potentially leading to litigation.

**Disadvantages of UT in lieu of RT**

i. Certain geometric features present restrictions for UT, e.g. attachments, skirts or nozzles adjacent to welds in the case of pressure vessels, or fittings in the case of piping systems.

ii. Variations in expertise – more capable service inspection companies/fabricators will engineer solutions to many, if not all ultrasonic ‘test restrictions’. Others readily give up and seek dispensation to exclude certain welds on the grounds of difficult geometry. It may be permissible to use the ‘test restriction’ excuse in the case of fabrication QC, but not in the case of FFS based on fracture mechanics principles. Inspections should be planned properly to minimise and/or deal with these effects. Fabricators/service inspection companies should be vetted during the pre-qualification process to assess their ability to deal with these situations.

iii. Certain flaw types are difficult to detect with UT (e.g. excess root penetration).

iv. Certain materials are not suited to inspection by UT, especially coarse-grained austenitic stainless steels.

v. The fracture-mechanics-based acceptance criteria of the code cases become more onerous for thin-wall materials and the benefits become diminished with wall thickness.

**Common mis-interpretations or mis-applications of the Code Cases**

**Procedures** – The purpose and intent of ultrasonic testing procedures themselves is very frequently mis-understood. A procedure should be derived from the construction code (in this case Section V, Article 4), incorporating the requirements of the code, but reflecting the equipment in use and the specific items to be examined. Work instructions/method statements and check-lists/calibration records should be defined in the procedures that are required to be used as living documents as each contract progresses. As the codes are intended to be used across a wide range of designs and situations, there is a certain degree of flexibility embodied within them. The American Society for Non-destructive testing (ASNT) personnel certification scheme SNT-TC-1A or CP-189 as referenced by the codes defines competency levels for individuals to be able to interpret the codes sufficiently to extract the information required in order to construct a procedure. It is common practice however, for fabricators and service inspection contractors to cut and paste blocks of text directly from the codes into their company procedures. Classic examples include code requirements for ‘an ultrasonic test frequency range of 1MHz to 5MHz’, or ‘two beam angles to be selected from 45°, 60° or 70°’ to be repeated word for word in the procedure. This leaves the actual inspection open to interpretation and inconsistencies will occur. These are simplistic examples that lead to relatively minor discrepancies.

The requirement to generate a procedure according to ASME V, Art 4, T-421 (and T III-422 in the case of TOFD and/or T IV-422 for Phased Array), including the identification and control of essential and non-essential variables is generally misunderstood, especially “the requirement for the procedure to establish a single value, or range of values, for each requirement”. This entire section has been observed to have been pasted verbatim directly into a procedure.

Much more serious cases are prevalent. As an example, the code cases stipulate that the ultrasonic examination shall include a volume of material to be included on each side of the weld
(the actual distance is dictated by the material thickness). The distance may be reduced to cover only the weld, Heat Affected Zone (HAZ) +6mm of base material, provided “The extent of the weld HAZ is measured and documented during the weld qualification process” and, “The UT transducer positioning and scanning device is controlled using a reference mark....”. It has been observed practice that the text is often lifted directly from the code case to the procedure – and then ignored. The end effect is that inadequate material is examined.

Very often, procedures are documents that are generated for audit purposes and technicians performing the work never see them or are even unaware of their existence.

**QA/QC:** Quality standards have developed quite strongly in recent years and there has been a strong focus on reliance on adherence to accredited schemes at the expense of technical audit, specification and supervision. In former times, certifying authorities employing personnel with technical knowledge and experience used to provide this form of oversight. Current QA/QC processes ensure that procedures are adhered to at the system level rather than digging into the technical detail. A key failing of this process is that QA/QC representatives tend to have competencies in QA/QC rather than in NDT. This does not detract from the highly important function of QA/QC as a process, but there is a competency gap that is currently not addressed.

**Ultrasonic inspection to Section V, Article 4:** The code cases do not stipulate which of the techniques described in Article 4 should be used. Conventional pulse-echo UT (fixed beam), Phased Array (PA) and the Time-Of-Flight-Diffraction (TOFD) techniques are all described and the user is free to select which of these may be used. The criteria of the code cases are that whichever technique is used, it must meet or exceed the minimum qualification criteria of the Code Case. It is unlikely that a conventional pulse-echo technique will meet the sizing criteria as these are more suited to techniques that make use of the tip-diffraction process such as TOFD and/or PA. Many of the factors that apply to interpretation and application of the code cases apply equally to interpretation and application of the base code itself, but this will not be addressed here unless it specifically relates to application of the Code Case.

**TOFD Supplementary coverage (as required by Article 4, Mandatory Appendix III):**

a) **Transverse flaws.** An angle beam examination is required for transverse flaws “unless the referencing Code Section requires a TOFD examination. In these cases, position each TOFD probe pair essentially parallel to the weld axis and move the probe pair along and down the weld axis. If the weld reinforcement is not ground smooth, position the probes on the adjacent plate material as parallel to the weld axis as possible.” **Caution:** The requirement to perform TOFD scans with the beam oriented parallel to the weld axis will not increase the probability of detection for transverse flaws any more than a scan with the beam oriented across the weld, possibly less so. This rationale stems from pulse-echo UT and does not apply to TOFD in the same way. Although the classic depiction of TOFD is where a crack is perpendicular to the ultrasonic beam, diffracted signals are still generated at the tips of transverse cracks when the crack’s primary axis is oriented parallel to the TOFD beam. An example is shown in Section V, Article 4, Non-Mandatory Appendix N. The code is wrong on this point, which does not help matters.

b) **Supplemental shear wave examination.** When TOFD is used, Article 4 calls for supplemental shear wave examinations due to the presence of the lateral wave and back-
wall signals. **Comment:** Unless the detection and sizing accuracies using these techniques can be successfully qualified using a qualification block(s), the supplemental shear wave examination techniques should be used in conjunction with the ‘good workmanship’ acceptance criteria of Section VIII. This is often overlooked in practice.

**Qualification block(s):** This is possibly the most universally misunderstood section of either of the Code Cases. The block(s) is (are) required to be manufactured by welding or the Hot Isostatic Process (HIP). The author has no experience of the latter being used for fabrication of entire qualification blocks, although this process has been seen to have been used in the nuclear industry to manufacture individual flaws of very precise dimensions. In this case the flaws are created by spark eroding the required flaw dimensions into one or both faces of two blocks of steel. The size of the blocks is somewhat larger than the introduced flaw. The (un-eroded) mating faces of the two blocks are then bonded together through the application of intense heat and pressure, creating a homogenous piece of material except for the now embedded, intended flaw. The block is then machined into a ‘bobbin’, which is implanted into the qualification block by welding. It is unlikely that HIP bonding would be used in the non-nuclear industry as there are other, less costly, if less precise methods of simulating planar flaws in welds. Reference to this fabrication process however, has led to speculation that blocks need not be welded, and that artificial flaws may be introduced from the ends of un-welded qualification blocks (presumably by drilling/Electro-Discharge Machining (EDM). Discussion of this can be found on [www.ndt.net](http://www.ndt.net) [Ref 7].

The Code Cases carried the statement regarding qualification block(s): “and shall contain a minimum of three flaws, oriented to simulate flaws parallel to the production weld’s fusion line...”. Interpretation of this definition has been carried out in various ways. The author’s interpretation of the intent of this is that the flaws should simulate the most difficult to detect of fabrication flaws in the form of a tight, smooth, planar flaw such as a lack of fusion (in isolation, i.e. not in combination with any other flaw). This is supported by the following statement also posted on the [www.ndt.net](http://www.ndt.net) website: “While the original ASME CC 2235 was not clear on this issue, the intent was to use artificial cracks - not side drilled holes or notches - as the reflectors. In addition, the artificial cracks should follow the bevel to simulate Lack of Fusion defects or similar. ASME is currently working on clarifying this situation. Michael Moles; Member, ASME Section V Ultrasonics Working Group”. It is positive to note that the 2008 Addenda to Section VIII requirements for qualification block flaws now reads: “...and shall contain a minimum of three planar (e.g. crack like) flaws, oriented to simulate flaws parallel to the production weld’s fusion line...”, although B31.3 CC181 still retains the original text. The author’s experience is that where an inspection service contractor or fabricator drives the process, qualification blocks may or may not contain welds, but they will contain drilled holes or notches, whereas where an end-user drives the process, qualification blocks will always be welded and will usually contain simulated planar welding flaws. The latter fall into the category of “crack-like”, in that they are tight, planar and preferentially oriented. Such flaws can be introduced by welding shims onto weld bevel faces (practice required!), or they can be procured from a specialist firm of sample manufacturers.

Cases have been observed in practice where 6mm wide buttress notches have been used to represent surface flaws in conjunction with TOFD procedures. This is incorrect on two counts. Firstly, a buttress notch represents a large, strongly reflective area when inspected from the opposite surface (quite unlike any natural planar flaw aligned with the weld fusion line), and
secondly, it is open to the surface. According to Section VIII MT & PT acceptance criteria, linear surface breaking flaws are unacceptable, so there seems little point in qualifying detection and sizing performance for flaws that are not permitted. This does not apply however, to slightly sub-surface flaws that are classified as surface flaws if the remaining ligament to the external surface is less than half the flaw height. More on this later.

Side drilled holes and EDM notches have frequently been observed as artificial flaws in qualification blocks. This generally speaking is a carry-over from the use of drilled holes and notches in calibration blocks described in Section V, Article 4. In this case, the artificial flaws are intended to create reflectors that are reproducible and easy to manufacture. Their purpose is to control accuracies of calibration, sizing, sensitivity and coverage. The purpose of implanted flaws within qualification blocks is an entirely different matter. Here the onus is not to repeat the calibration process, but to verify the performance of the calibrated UT set-up on simulated planar welding flaws. It should be borne in mind that a true lack of side wall fusion is often a very tight flaw that has negligible width or gape. In the most extreme of situations, the weld pool may solidify alongside a weld bevel face without actually forming a bond, and in this case it is no more than a molecular separation. Such a flaw will be partially opaque and the tips will have negligible width. Flaw opacity and morphology are both important for pulse-echo techniques (including phased array), and tip condition is important for techniques that rely on tip diffraction such as TOFD or phased array. Drilled holes and notches satisfy none of these conditions and should not be considered for qualification blocks.

A further consideration with qualification blocks is the number of flaws required. The code cases stipulate “a minimum of three planar (e.g., crack like) flaws, oriented to simulate flaws parallel to the weld fusion line. The minimum criteria of only ‘three flaws’ tends to be the automatic choice in practice, and in the author’s view, this is likely to be inadequate in most, if not all cases. However, there are two alternative interpretations to this requirement:

i. the requirement for one flaw at each surface and one sub-surface flaw is to demonstrate overall system performance through the full thickness, or,

ii. the requirement to demonstrate system performance covering each depth zone as described in Section V Article 4, for all bevel angles.

In practice, fabricators and inspection service companies will opt for i. above, but would end-users be more comfortable with qualifying system performance throughout each zone and bevel angle?

Another factor which is widely ignored is the qualification block geometry. Table T-421 of ASME V, Article 4, 2008 Addenda provides mandatory requirements for UT examinations. This table defines ‘essential variables’ for which a single value or range of values are to be established. It goes on to say that “when procedure qualification is required by the referencing Code Section, a change of a requirement in Table T-421 identified as an essential variable from the specified value, or range of values, shall require requalification of the written procedure.” The code does not specify the required calibration block geometry, although the 2008 Addenda to Section VIII does state that the qualification block must be within 25% of the thickness to be examined. It follows however, that if the component geometry limits defined in the procedure (essential variable according to T-412) are exceeded, then additional qualification block(s) will be required. This translates to a requirement for
multiple calibration blocks covering the full range of thicknesses to be examined, material combinations and component geometries.

Other factors influenced by price/productivity pressures

**Welding quality.** As stated earlier, a 39mm long by 4mm high subsurface flaw would be acceptable in a 50mm thick pressure vessel or pipe weld. Based on observations in the field it is suspected that some welders or fabricators, on realising that it would in fact be hard to produce a flaw of these dimensions, would be inclined to concentrate on quantity rather than quality. This is especially the case if they are incentivised on the basis of production. This is compounded by the fact that in theory at least, unlimited quantities of volumetric flaws are permitted.

**NDT technician competencies.** Large numbers of technicians have been required by industry to work in accordance with the code cases and there has been a tendency to rush these through the certification process. This has been achieved by streamlining the training, examination and certification process to concentrate on simplistic, clear-cut and unrealistic flaw conditions. Non-Mandatory Appendix N of Section V, Article 4 (TOFD Interpretation) could be construed as misleading in this regard. Very clear-cut examples of classic flaw interactions are described. The surface-breaking flaw for example, is a notch, not a real fusion flaw or crack, which behave very differently. Complete loss of lateral wave signal is a very, rare event. The Appendix implies that TOFD indications can be identified, characterised and sized from the TOFD data alone. In extreme cases this is sometimes possible, but they really are rare occurrences. In real-life, TOFD indications need to be investigated using additional TOFD scanning and/or pulse-echo techniques to differentiate planar from volumetric flaws based on their reflectivity. Please see Figure 2 as an example of complex flaw formations.
Figure 2. TOFD Data - Complex flaw formations, possibly arising as a result of abuse of the relaxed acceptance criteria of the Code Cases, but leading to difficulties with interpretation for the operator trained on clear-cut, idealistic flaws.

This is an example of what occurs regularly in the field. In this case it is manual welding, and is the result of poor workmanship. It probably comprises of a combination of slag inclusions, porosity, lack of side-wall and lack of inter-run fusion. The possibility of cracking cannot be discounted, but under the fracture-mechanics-based acceptance criteria, flaw type is immaterial, only flaw dimensions are required for acceptance purposes. In the author’s experience, provision is not made for either manual or automated pulse-echo characterisation (discrimination between planar and volumetric flaws) of complex flaws and this situation is not addressed by codes, standards or procedures. Codes and training materials do however, refer to buried flaws being recognisable due to phase reversals, and far-surface flaws being identifiable due to effects at or after the back-wall. In the author’s experience, these idealistic situations do not arise in practice. The only way to deal with the above condition is a combination of advanced signal processing and comprehensive (and time consuming) evaluation by an experienced technician conversant with both pulse-echo and TOFD. Similar limitations apply to phased array, where complex interactions can occur with direct and mode-converted responses from complex flaw formations where ‘masking’ can also be an issue. There is a danger of an inexperienced technician being trained to only look for ‘tops & bottoms’ or back-wall effects as evidence of planar flaws. This is a potentially dangerous situation, and it should be dealt with early on in the production process. Several cases have been experienced where similar conditions were exposed only after all welding/fabrication was completed.

Conclusions
It can be concluded that there are significant disparities between the manner in which code case inspections are, or could be applied in practice. On the one hand, the process can be applied in the spirit with which it was intended, possibly with enhancements that enable component quality to be optimised, and on the other, the code cases can be interpreted to deliver lowest project quality, but with highest risk.

It can also be concluded that if applied in the spirit with which they are intended, the code cases can lead to a requirement for a large quantity of costly qualification blocks and high levels of qualification activity, which could have the potential to impede project timescales. Although more time and expense should certainly be incurred in this area than is current practice, there are ways in which to manage this process efficiently. This is elaborated further in the next section.

Where there is insufficient attention to pre-qualification and technical supervision throughout the project, successful bidders for construction NDT projects are likely to be those that provide a minimalist interpretation of code case requirements that lead to unacceptable project risks for the end-user.
**Recommendations**

It is recommended that the following process is adopted in the case of new-construction projects where ultrasonic examination is carried out in lieu of RT (Section VIII, Div 2, Part 7) and/or ASME B31.3 Code Case 181:

i. The end-user to generate a specification of performance criteria for the fabricator/inspector to follow. Simply to state that the inspection must meet code requirements is insufficient. Fabricators and inspection service companies are under intense pressure to meet timescale and cost targets and will adapt their interpretation of codes to meet these ends.

ii. Risk assessments should be carried out on tender submissions. These should address factors such as the probability of project over-runs, expected weld quality, and should be based on reviews of current competencies, demonstrated capabilities, experience and proven track record. Dependency on quality systems alone is inadequate.

iii. Technical supervision. A competent technical authority should be engaged to monitor the process from pre-contract audit through qualification, inspection and final data review. This should also involve independent review of data to assess quality and reliability of interpretation.

iv. It should be contractually agreed that the inspection body is responsible for work that is technically non-compliant with provision for repeat and/or escalation of inspection activity.

v. The design of qualification blocks, including the type of artificial flaw should be defined in the project specification and approved by the technical authority prior to project commencement. Qualification blocks should reflect actual component geometries, material combinations and wall thicknesses.

vi. Qualification flaws should address all inspection zones, flaw orientations (including transverse flaws) and weld bevel angles.

vii. Procedures, training and certification criteria should make provision for interpretation and characterisation of complex flaw formations and should address the ability to accurately measure the ligament of remaining material between a flaw tip and the external surface in the case of near-surface flaws.

viii. The inspection process should commence at the welder and weld procedure qualification stage in order to optimise welding quality in advance of production welding. This should become a hold point.

ix. Inaccessible welds. Inaccessible, or partially inaccessible welds are often classified as a ‘test restriction’, and excluded from examination. As described earlier, this could be a matter of convenience. Designs should be reviewed by a technically competent authority prior to commencement of construction.

x. A possible alternative to the requirement for extensive flawed samples is to approach qualification in the spirit of a nuclear industry qualification. ASME codes make provision for variations subject to the agreement of all parties, provided the variations at least meet the minimum code requirements. Qualification is required in the nuclear industry according to ASME XI, Appendix 8, Performance Demonstration [Ref 8]. In this case, the performance criteria of an inspection are defined, and the inspection service contractor is required to qualify equipment, procedures and personnel using a combination of open and blind trials on test samples through an independent body. The European nuclear community established the European Network for Inspection Qualification (ENIQ) [Ref 9] through the
European Joint Research Commission (JRC) as a mechanism to maintain qualification standards whilst minimising the requirement for qualification samples. This is achieved through a vigorous process involving expert judgement/reasoning, mathematical modelling (e.g. CIVA [Ref 10] and UMASIS [Ref 11]) and practical demonstration. Prior experience with qualification may be taken into account. Adoption of this process could enable an initial base-case to be qualified followed by qualification of variables on a case by case basis. ENIQ was developed by the nuclear community, but it is intended to apply to non-nuclear applications also. It has been used for several oil industry applications in recent years [Ref 12].

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