Draft report of Welding Task Group

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Executive Summary

The goal of this welding task group was to develop a list of welding standards for nuclear construction and repair that merit attention, together with specific examples of what aspects should be addressed. This included: what changes should occur in current standards to make them more streamlined (easier to read and follow, reduced construction times), and safer (more precise control of key parameters), as well as pointing out technical advances that have occurred since their last major revision and should be addressed within the standards. We based our list of needs on data collected from users of the standards: specifically those who construct nuclear plants or will be the eventual owners, and so responsible for repairs. Then, the technical people on the committee were able to identify the technology that could respond to these needs. Minutes of the meetings and other task group documents are available in the welding task group folder, at:
http://publicaa.ansi.org/sites/apdl/NESCCDocs/Forms/welding.aspx

Welding is central to nuclear construction and repair activities, and the considerable volume of code language devoted to it indicates how crucial it can be in terms of inspection, fitness for service, and the response of materials to design and out-of-design loads and environments. While welds may make up only a few percent of the structure on a volume basis, the labor and technology necessary to produce them means that welds can make up 10% or more of the cost of the cost of the final structure. Thus, welding costs can be such a large component of plant construction and maintenance that they drive the development of innovative processes and techniques to increase effective deposition rates, increase weld quality, and decrease weld time. Also, just as a chain is only as strong as its weakest link, the integrity of a structure depends equally on the properties of the plate, the weld, and the heat affected zone in equal measure. Thus, substantial effort must be given to understanding the properties of the weld, and the interaction between the weld and the plate, within the heat affected zone.

The Key Issues section, on page X, lists the areas were attention should be focused. The issues were organized into the categories of:

- repeated requalification of welding procedures (why do we have to repeat what we have successfully done before?)
- keeping individuals standards aligned with each other
- better certification of welding personnel, especially welding engineers
- making better use of the inspection capabilities of phased array technology, and
- making repair decisions based on fitness for service assessments rather than workmanship standards.
Introduction

The Nuclear Energy Standards Coordination Collaborative (NESCC) is a joint initiative of the American National Standards Institute (ANSI) and the National Institute of Standards and Technology (NIST). NESCC was created in June 2009 to identify and respond to the current standards needs of the nuclear industry. As the members identified topical areas that required attention (such as standards that had not kept pace with technological developments), they formed targeted task groups. Technical discussions and preparation of reports with recommendations were drafted within these task groups, on subject areas such as concrete, polymer piping, and welding. After review and incorporation of comments from the NESCC, these reports are published and forwarded for consideration by the relevant standards committees. More details on the NESCC and its activities can be found at: http://www.ansi.org/standards_activities/standards_boards_panels/nescc/overview.aspx#.UVjwljeU_Sg

Welding is central to nuclear construction and repair activities, and the considerable volume of code language devoted to it indicates how crucial it can be in terms of inspection, fitness for service, and the response of materials to design and out-of-design loads and environments. Welding costs can be such a large component of plant construction and maintenance that they drive the development of innovative processes and techniques to increase effective deposition rates, increase weld quality, and decrease weld time. Thus, there were sufficient issues identified in welding to justify the formation of a task group dedicated to this topic.

The task group on welding was proposed within the NESCC during 2011, and had its first meeting (face-to-face) in November 2011. Following meetings were handled primarily by teleconferences (about eight or nine the year) and periodic face-to-face discussions. The initial membership was about 10, and but grew to over 50 within the first year, as we identified additional participants who were interested in contributing, and who brought in critical skills and knowledge.

The goal of the welding task group was to develop a list of welding standards that merit attention, together with specific examples of what aspects should be addressed. This included: what changes might occur current standards to make them more streamlined (easier to read and follow, reduced construction times), and safer (more precise control of key parameters), as well as pointing out technical advances that have occurred since their last major revision and should be addressed within the standards. Minutes of the meetings and other task group documents are available in the welding task group folder, at: http://publicaa.ansi/sites/apdl/NESCCDocs/Forms/welding.aspx

The Key Issues section, on page X, lists the key areas where attention should be focused. Later, specific recommendations are made.
Relevant Standards Development Organizations (SDO's) and Documents

ASME
For over 100 years, the American Society of Mechanical Engineers has been formulating standard rules for the construction of steam boilers and other pressure vessels. The rules applicable to the welding of nuclear components fall within the responsibility of the Boiler and Pressure Vessel Committee. One of their documents states “The committee's function is to establish rules of safety, relating only to pressure integrity, covering the construction of boilers, pressure vessels, transportation and nuclear components, and in-service inspection for pressure integrity of nuclear components and transfer tanks, and to interpret these rules when questions arise regarding their intent.”¹

(additional overview of the organization will be added by Walt Sperko (if needed), and later we will get volunteers to add overviews of relevant welding standards for nuclear applications. Walt, could you also develop a short summary of Section IX?)

AWS
Founded in 1919, the mission of the American Welding Society is to advance the science, technology and application of welding and allied joining and cutting processes, including brazing, soldering and thermal spraying. While not developing codes and standards specifically for nuclear applications, AWS develops and maintains standards for general structures (such as the AWS D1.1 Structural Welding Code), as well as standards for welding processes, personnel qualification, and procedure qualification that feed into other codes and standards, such as those of ASME.

(further overview of the organization will be added by Annette Alonzo (if needed), and later we will get volunteers to add overviews of relevant welding standards for nuclear applications)

ASTM
(Are there any volunteers to write a summary of ASTM, one that would be parallel to the other two descriptions?)

Key Issues

- **Avoiding senseless requalification of welding procedures.** Why do we need to requalify again and again to prove what we already know? This repetition can be greatly reduced through producing standardized welding procedures that are widely available and meet the requirements of multiple codes, such as ASME Section IX and AWS D1.1. The following italicized text (on the next few pages) summarizes an EPRI guideline that reduces the production of multiple procedures to meet the requirements of both codes.

(Note that the following italicized content was provided by Phil Flenner with a few editorial changes inserted by Tom Siewert, and seems to be appropriate for being referenced in our report. I specifically ask the EPRI members of our task group to determine whether it is appropriate to include it in its entirety, or whether it should only be summarized and referenced.)

**SYNOPSIS OF EPRI GUIDELINE FOR USING ONE WELDING QUALIFICATION CODE**


Note: While this synopsis is based on the above referenced EPRI Technical Update, that document is currently under revision and some changes are being made to address changes in AWS D1.1 and ASME Section IX since it was originally developed.

“Abstract:

The use of multiple welding qualification codes has long been a problem for plants that have a number of different design codes. The most frequently used welding qualification codes are the ASME Section IX, Welding and Brazing Qualifications, and AWS D1.1, Structural Welding Code – Steel, although there are a number of others that could be used in applications such as nuclear power plants. Regulatory requirements are not consistent in this issue in that the use of ASME Section IX may be required for 1) all safety related applications, 2) only ASME B&VP and B31.1 applications, or 3) for all safety related applications provided the requirements of AWS D1.1 are met for the structural applications. Since AWS D1.1 allows the use of other standards for welding qualifications with consideration of specific structure and/or service conditions, it can be said that ASME Section IX welding qualifications meet the requirements of AWS D1.1 if these conditions are appropriately considered. Although the regulatory requirements differ with the requirements for the balance of plant systems in nuclear power plants, the same approach can be taken with regard to welding qualifications for structures.

This guideline provides the justification and direction needed to use ASME Section IX welding qualifications for both ASME B&VP and B31.1 applications and for structural applications. It
would not be needed where the regulatory requirements specify the use of ASME Section IX welding qualifications for all applications. It should be useful in justifying a single tiered approach to welding qualifications, using only the Section IX qualifications, where both AWS D1.1 and ASME Section IX welding qualifications are specified. The approach taken is to show that ASME Section IX qualifications are appropriate for the structural applications and therefore become an acceptable alternative within AWS D1.1.

The basic purpose of both ASME Section IX and the welding qualification rules of AWS D1.1 is to control the special process of welding. Nuclear quality assurance requirements include a specific criterion to address special processes which are succinctly defined in ASME NQA-1 as:

-a process, the results of which are highly dependent on the control of the process or the skill of the operators, or both, and in which the specified quality cannot be readily determined by inspection or test of the product.

There are obviously differences between ASME Section IX and AWS D1.1 on the exact approach to be taken to achieve the required control, but the goal is the same. We must have adequate direction (WPSs) on how to make a weld that has the properties we desire and we must show that the welders or welding operators that weld in accordance with these procedures are capable of providing sound welds.

The approach taken in the EPRI guideline document was to use the permission granted by AWS D1.1 to allow the engineer to accept WPS qualifications or performance qualifications done in accordance with other standards. The EPRI guideline basically provides an approach to justifying these acceptances. No attempt was made to justify the use of welding qualification standards other than ASME Section IX (e.g., AWS B2.1) since it would be highly unlikely that any other document would be acceptable to the ASME Codes and Standards. However, since AWS D1.1 already references AWS B2.1 which is very similar to ASME Section IX, some benefit was seen in using this similarity.

There was no attempt to address structural design requirements for welded joints which are well defined in AWS D1.1. The guideline only addressed the use of ASME Section IX welding qualifications to be used as acceptable alternatives to the AWS D1.1 welding qualifications. This approach would therefore allow a basically single tiered approach for welding qualifications to be used for both ASME pressure retaining applications and for AWS structural applications. The basic intent of the guideline was to address the use of a single tiered approach for welding qualifications in existing nuclear plants since many Safety Analysis Reports were written such that the ASME Section IX qualifications were required. However, it should be a consideration to use the same approach to provide for welding qualifications for new construction to eliminate duplicative welding programs.
The approach used for the engineering acceptance was to compare existing requirements for and acceptable alternatives to the welding qualifications in AWS D1.1 to the welding qualifications required by ASME Section IX. AWS D1.1 specifically accepted AWS B2.1 welding qualifications which provided a convenient comparison since B2.1 is very similar to ASME Section IX. Although the guideline is currently being revised to update to current Code requirements, the acceptance approach was summarized as follows in the existing EPRI Guideline:

“GUIDELINE FOR USING ASME SECTION IX QUALIFICATIONS FOR AWS D1.1 WELDING

The American Welding Society Standard D1.1, Structural Welding Code – Steel, provides the requirements for welding qualifications, for welding procedure specifications (WPS) and welder/welding operator, for welding being done on structural components. The AWS D1.1 Code allows and accepts the use of welding qualifications in accordance with other standards however, provided the Engineer consider the effects on the specific structure and the service conditions. This guideline provides the direction needed for this consideration.

The designer must specify:

1. The base material to be used.
2. The weld size.
3. The effective throat of the weld if less than full penetration.
4. The weld joint design

The ASME Section IX WPS must be qualified to weld:

1. The P No. or S No. of the structural material being welded or the specific material being welded.
2. Using the filler metal specified by the design.
3. On impact tested material if required by the design.
4. Within the ranges needed for the structural design (e.g., PWHT)

The ASME Section IX welder or welding operator must be qualified to weld:

1. Using the WPS that is required.
2. Under the access conditions that are present.

The post weld examination and verification of the weld size and effective throat shall be in accordance with the AWS D1.1 Code.”

The AWS D1.1 requirements for acceptance of qualifications to other standards are expected to change over time, but this shouldn't change the ability of the engineer to accept the qualifications but rather only modify the approach.
While this approach minimizes the duplication of effort needed to meet both the ASME and AWS codes, it is effectively a workaround. It would be much more efficient if so welding procedures could be harmonized between the two codes. We would recommend that the AWS B2 committee (which feeds into ASME Section IX) and AWS D1.1 committee to develop a liaison so their welding procedures could be as similar as possible, or ideally, identical.

Also, the available prequalified welding procedures distributed by AWS only cover a fraction of what is needed, and some of them are missing key attributes such as impact toughness for lower temperature applications or FN limits (ferrite number is a measure of the amount of retained delta ferrite in primarily austenitic welds, and is used to assess certain physical and mechanical properties of a weld). How do we get these additional procedures and information added to existing prequalified procedures? (One comment was that the large companies have this data already, but have no incentive to share it with others. Can we come up with an incentive to pool such data?) Alternatively, these committees could develop a proposal to the ASME Foundation (which funds research tomb make the application of the code more efficient) to develop new and expanded procedures.

a. **Requalification for metallic materials.** Does automation of the welding raise new issues? Should more procedures be available for SAW? Phil Flenner will develop a summary of what is needed.

b. **Requalification for nonmetallic materials.** The issues appeared to be different for nonmetals. Walt Sperko will assist on this section.

- **Keeping individuals standards aligned with each other** (especially those developed by different organizations). For example AWS B2 requirements are currently well aligned with those of ASME Section IX, and hopefully they will stay that way. Might AWS D1.1 accept the AWS B2.1 method of qualification, at least as an option? (This working group being led by Jeff Fluckiger. (A recent update is inserted below). A lot of this material is now covered in the text above provided by Phil Flenner. Should we bring some of the material in the previous bullet down into this section, or should they be combined? )

“Might AWS D1.1 accept the AWS B2.1 method of qualification, as least as an option?” has been addressed at length and Annette Alonzo could provide AWS Technical Activities Committee (TAC) history on the subject. Some time ago, TAC made the decision that B2.1 was the qualification standard for AWS and that the application codes were to begin the process of incorporating B2.1 and eliminating their qualification sections to the extent possible. Several of the AWS application codes worked diligently in the direction requested but D1.1 has been very resistant. D1.1 finally incorporated a statement within the code that allows the use of B2.1 with the Engineers approval. Meeting after meeting, when D1 was asked to report on the progress made toward the incorporation of B2, the response was that they had polled their customers and their customers wanted all of the requirements contained between the two red covers of D1.1. No
technical differences were ever identified. The hold out is simply based on marketing and personal preference.

AWS B2.1 is the genesis for the Standard Welding Procedure Specifications (SWPS). The alignment that currently exists between ASME Section IX and AWS B2.1 is based on the fact that B2.1 provides the SWPSs. Some feel that the existing B2.1 SWPSs are inadequate and need to include notch toughness and ferrite number. Another view is that the existing SWPSs would not be revised but a new contingent of SWPSs would be developed to meet the desire of the nuclear need. Some of the existing PQRs in the WRC database would be appropriate to support the additional needs and of course as has been discussed others would need to be in place. B2.1 currently identifies the process of the industry submittal (donation) of PQRs to WRC and the other option is to obtain funding, and resources to develop new PQRs. When these new SWPSs are created, the ranges for thickness and other variables can be customized to meet the need as long as the PQRs support it. The limitations currently existing in the SWPSs is intentional and is the committee line to “stay in the middle of the channel where the water is deep.” In other words, the committee has made very conservative decisions even though the B2.1 standard allows broader application.

I think the code requirements could be combined. The overall effort is the same in reducing the number of standards/codes to comply with. The bottom line is there is no identified technical difference for qualification between AWS D1.1, ASME Section IX or AWS B2.1. They all prove or validate the mechanical compatibility between a base metal and a filler metal under certain conditions and that is all the procedure qualification is meant to be. We run in to trouble when we try to get the PQR to do other things. The same holds true for performance qualification in that the test is to adequately demonstrate the ability of the welder to deposit sound filler metal while following the guidance (limitation) provided in the welding procedure specification. Again we run in to differences when we try to have that performance test do other things.

Jeff is working with Walt Sperko and Mike Bernasek to include ASME Section IX data in his comparison of codes. Also, the AWS B2 committee is identifying any additional procedures that should be standardized, and is looking to obtain the information to support them (including toughness data and FN values for stainless steel). One comment during the discussion was the thickness ranges should extend up to 1.5 inches. Also, Clyde Morell of NRC offered to assist in identifying how automation of the welding process might affect the qualification of personnel.

- **Personnel certification of welding engineers** (There is a drive toward better documentation of the certification and training of personnel (like ISO requirements), yet the Professional Engineering registration in welding has been discontinued in the US. Is something else needed to fill this gap? Perhaps something like the Certified Welding Engineer program? (Meanwhile, Dick Holdren is trying to reinstate the PE in welding.) This includes more than just a PE, but also titles such as Welding Supervisor or Welding Coordinator. (An AWS Special Committee has looked into this issue, and says that if further clarification of the issue will occur within the AWS
technical activities committee.) (Note: at about this point in the introduction we need to define the different terms and programs, such as PE, C Eng, and CWEng.)

(More detailed outline of the situation)

Objective

To avoid courtroom battles at all costs and to make sure that language is in place so that, if they occur, they don’t become sidetracked by the merits of PE vs C Eng or similar.

Expectation

- The next generation of Nuclear Power plants for the USA will be International with respect to design and build.
- The overall design code for power plant will be ASME.
- Contracts will be let under USA laws.
- US states will require PE’s.
- All contractors will be required to be ISO certified/compliant.

Observations

- The US contract will require PE’s.
- ISO requires the use of registered welding engineers.
- There is an open loop that can best be resolved with reciprocity as it is:
  - Not feasible to have enough US PE’s operating at overseas fabrication/design organizations.
  - Not feasible to have enough internationally qualified welding engineers operating at US fabrication/design organizations.
- A PE in any discipline can be responsible for welding operations.
- History shows that without qualified welding engineers, fabrication costs and risk will be higher.
- There will be a shortage of welding personnel at all levels and we can’t afford to get sidetracked with certification issues or the product will suffer.

Thoughts

- Reciprocity between PE and C Eng and International Welding Engineer Qualification should be included in contract language.
- Harmonization should be a near term as opposed to a very long term goal for certification bodies in a global collaborative world.

- Making better use of the inspection capabilities of phased array technology. (Contributed by Michael Moles and Eric Sjerve)
The dominant player in phased array codes is ASME (the American Society for Mechanical Engineers), with associated standards bodies (e.g. ASTM, API). ASME recently published a full series of Mandatory AUT (Automated Ultrasonic Testing) and Phased Array (PA) Appendices in Section V (NDE). These now cover most aspects of advanced ultrasonic inspection (including TOFD), and are specifically aimed at boiler and piping weld inspections. The three new AUT Appendices essentially replace the old Code Case 2235, but are significantly easier to read and understand; however, they do not include acceptance criteria as these will be developed in other ASME reference Sections. This section summarizes the requirements of the five new Mandatory Appendices, and their implications. In addition, a short description of other code bodies working on phased arrays is included (ISO, Chinese, Japanese, and the American Welding Society). TOFD Codes will be briefly described, along with Guided Wave developments.

Phased Array Codes, i.e. ASME

The ASME Boiler & Pressure Vessel Code [1] covers all aspects of pressure vessel manufacture, including design, welding, and inspection. The Code itself is divided into twelve Sections, with NonDestructive Examination (NDE) labelled Section V [2]. Typically, the NDE portion does not write acceptance criteria for defects; that is the domain of other (referencing) sections, which tend to be more Structural Integrity-based. In ultrasonics, the ASME Section V UT Working Group decided that it was time to introduce new techniques, specifically AUT (phased arrays and Time-Of-Flight Diffraction) into the Code. As such, they started back in the early 2000’s to write a TOFD Code [3], along with a TOFD Interpretation Manual [4] and TOFD guidelines [5]. Subsequently, ASME started working on phased array Code Cases (eventually publishing five), and modifying Code Case 2235 for AUT [6]. (The original Code Case 2235 was not published by Section V, but by other Referencing Sections, so it included accept-reject criteria.) At this time, the ASME B&PV and related family are the only published phased array codes.

ASME Phased Array Codes

ASME started with the simplest application – manual phased arrays with a single beam [7]. This was subsequently followed by two other manual phased array codes, S-scans and E-scans [8, 9]. However, encoded scanning (linear scanning) proved more challenging. (Note that there are significant differences between manual and encoded scanning, as shown in [10]).

While it was obvious that phased array S-scans could cover welds (both well and quickly), it was not so obvious how to do it (legally). After considerable thought, it was determined that modeling with some experimental backup was the best route. Figure 1 shows an example of modeling S-scans on a simple V-butt weld. Basically, if one wants to inspect a weld at +10 degrees bevel incidence angle (BIA), one needs to use at least two separate S-scan angles, but the results are scalable. For five degree BIA tolerance, three S-scans would be needed.
Figure 1: Top, 5° tolerance; requires three S-scans per side.

Middle: 10° tolerance; requires two S-scans per side.

Bottom: 10° tolerance; scalable.

This was subsequently followed by experimental data, as shown in Figure 2 [11]. The results in Figure 2 on real defects showed that the bevel incidence angle should be within ±10°
(approximately), so ASME worded the code accordingly. “... at an appropriate angle” [15]. This pushes the procedure on to the Level III for approval.

Figure 2: S-scan amplitudes from various artificial defects with ± 10° lines shown.

The last two phased array code cases were published for encoded S-scans and E-scans [12, 13]. These five Code Cases were later amalgamated into two Mandatory Appendices in the 2010 edition [14, 15]. Other factors, such as scanning speed, weld coverage, and step size, were either already covered in Section V Article 4, or were “common sense”.

**ASME Code Case 2235**

ASME published all three AUT Codes [16-18] and two phased array codes in July 2010, so it is now “legal”. These three Mandatory AUT Appendices are similar to the original CC 2235, but are much clearer. One Mandatory Appendix is for workmanship criteria, one for Fracture Mechanics (or Engineering Critical Assessment), and one for procedure qualification. Essentially, the procedure qualification Appendix requires a non-blind test for operators, and for new
construction, EDM notches or similar can be used. Overall, the new Mandatory Appendices (particularly [18]) are similar to Code Case 2235.

What Do Published Phased Array Mandatory Appendices Require?

With phased arrays, much is common sense. However, there are a few details that should be highlighted:

**Calibrate all waveforms**

This is independent of selected angle or path length, and is mandatory. For OmniScan, this is not a major problem as Olympus has set up the Auto-TCG function for calibrating manually. Figure 3 shows an example of the calibration approach, and Figure 4 some typical calibration results.

![Figure 3: Auto-TCG function on OmniScan.](image-url)
scanning, a Scan Plan is both essential and mandatory. While a scan plan can be drawn on the back of an envelope, it is a lot quicker, easier and more flexible to use a computer program, as shown in Figure 5 [19]. These programs are practical and easy to use – and relatively economical.

Figure 4: Scans showing side-drilled hole calibration amplitudes at 45, 55 and 65°.

Scan Plans

For encoded PA
**Figure 5:** Sample scan plan of a 10 mm pipe using two S-scans showing coverage.

**Scanning speed, step size etc**

These rules are basically common sense. If you scan too fast, there will be data drop-outs, and ASME has defined what is tolerable. Step size is fairly logical too; coverage is dictated by the -6 dB rule.

**American Society for Testing and Materials (ASTM)**

ASTM doesn’t write codes as such, but it writes many Standard Practices (SP). SP’s differ from codes as they do not dictate “what” the operator should do (like the ASME Code), but they state “how” the inspection should be done. ASTM is quite closely aligned with ASME, and ASME accepts ASTM SP’s on a regular basis and incorporates them into the ASME Code. As such, many of the ASTM SP’s supplement the ASME Code.

**ASTM E-2491.** This is the basic SP for operating phased arrays [20], and describes a standard guide for evaluating performance characteristics of phased array systems.

**ASTM E-2700.** This is a Standard Practice for contact inspection of welds using phased arrays, and thus is relevant to nuclear inspections – new or in-service [21].

**ASTM E-2904.** This Standard Practice is for characterizing and evaluating the arrays themselves, and also should be important for nuclear inspections [22]. However, E-2904 only addresses linear arrays, not more complex arrays like matrix or specials.
In addition, there are many (conventional) ASTM ultrasonic NDE Standard Practices that could be used for nuclear construction, e.g. E-164 for contact testing, E-317 for evaluating characteristics, and E-1316 for definitions. These and others can be found in [23].

**What ASME Codes Do NOT Address**

The short answer to this is: “Quite a lot in theory, though not so much in practice”. There are whole areas of phased arrays not addressed, such as matrix arrays, Transmit-Receive Longitudinal wave-Phased Arrays (TRL-PA), stainless L-waves and other specials. ASME Codes do not address anything but simple linear arrays for weld inspections. These may cover the vast majority of applications, but they certainly not all. For example, austenitics (including cladding, nickel, Inconel, Waspalloy etc.) are generally not covered.

If the inspector wishes to inspect one of these more exotic materials, then they will need to perform a Performance Demonstration, as defined in Section V Article 4 Mandatory Appendix IX [18]. This Appendix is not particularly demanding, and is not aimed at complex inspections or geometries. However, it is well within the Authorized Inspector’s ability to request a more demanding, more realistic inspection on a mock-up component. In fact, the ASME Section V UT Working Group has already decided unofficially that a Performance Demonstration is the “way to go” for AUT generally, for inexperienced operators as well as experts.

Another area not touched by the ASME Code is advanced phased array techniques like Total Focusing Method (TFM), also called Volume Focusing and various other terms. Here, the array is not used in conventional pulses-echo format, but is used for repeatedly pulsing on adjacent elements to build up a SAFT-like summary of the component, then reconstructing via computer. At this time, the TFM method is largely in the laboratory, though there are a few external companies commercializing it. There are a few commercial products (e.g. [24] ), but not a lot yet. Again, the ASME solution would be to require a Performance Demonstration. If the demands are too complex, then an additional trial may be required along the lines of Section V Article 14 [25]. Section V Article 14 is an alternative to Mandatory Appendix IX, and offers various procedures up to a full-blown POD study.

**American Petroleum Institute (API)**

API is also closely associated with the ASME family, and collaborates with ASME in some areas (e.g. the Post Construction Code-3 document, which is a risk-based inspection). In general, API accepts phased arrays in such practices as RP2X, API 620, and API 1104 [25].

**American Welding Society (AWS)**
AWS has not exactly been progressive towards accepting phased arrays. The D1.1 inspection code was written around 40 years ago, and there is remarkable reluctance to make any changes. However, there are two areas where phased arrays are penetrating: manual and S-scan linear encoded scanning (see [10] again for the differences).

**Manual Phased Arrays.** The AWS D1.1 Code essentially permits the use of manual phased arrays, if the appropriate developments are taken [26]. These include manufacturing the wedge so that it will generate all the specified angles (45, 60 and 70°), and manually scanning to follow the Code. Both Olympus and GE have been promoting this approach over the last few years. Figure 5 shows a photo of an array and wedge combination used for AWS manual phased arrays.

![Photo of AWS manual phased array with wedge](image)

**Figure 5: ONDT AWS manual phased array with wedge.**

**Encoded Linear Phased Arrays.** This area has been subject to major discussions in the past few years at AWS D1.1. Initially, the discussion was on oscillating the probe. This was shown to be unnecessary [27]. Then more recently, the main discussion has effectively centered on acceptance criteria. At an AWS meeting in late February 2013, the decision was made to base the upcoming AWS phased array (annex) on Annex S, and use their acceptance criteria. This draft annex has just gone out for further discussion and re-ballot, and may be available soon. AWS clients are pushing the Code committee to formalize phased arrays so that they are generally available.

**What Are The Differences Between ASME and AWS?** Basically, the differences are almost entirely philosophical. The technology is essentially the same; however, the approaches of these
two organizations is fundamentally different from an inspection viewpoint, as their requirements are typically different.

PA Codes from Other International Code Bodies

Again, it should be emphasized that all other code-writing bodies are still preparing their phased array codes – ASME is alone with published PA Codes. Phased arrays seem to have taken the world by storm, partly because there has been a driving need for something to replace film radiography. (Note that Computed Radiography and Digital Radiography are now both available commercially on the market).

ISO PA Code. ISO is nominally the “world standard”, but has been typically bureaucratic in its development as it requires global approval. The first ISO effort was largely based on TOFD (not surprising as ISO and TOFD are largely run from Europe); the second effort was much better, and this author wrote only six pages of comments. However, the final product should be good, and acceptable.

Chinese PA Code. This draft code is relatively new, and is based largely on workmanship acceptance criteria, and perhaps on Dynamic Depth Focusing. (Note that, even though Olympus developed DDF a decade ago, we do not recommend it for weld inspections). The Chinese PA Code is scheduled for a final meeting in June 2013 - maybe.

Japanese PA Code. Like ISO and the Japanese, this code is not progressing particularly quickly. No feedback on progress or development.

TOFD Codes

Since both phased arrays and TOFD use encoded linear scanning, common sense says that the two should be used in conjunction. As it happens, the two are essentially complementary, as the strengths of one technique are the weaknesses of the other, and vice versa. In fact, the Probability of Detection of the two techniques combines appears to be higher than either independently, and much higher than manual ultrasonics or film radiography. The general concept can be shown in the attached POD study from the Dutch Welding Institute (see Figure 6); using a combination of TOFD and PA should give a POD of over 90% using this data.
TOFD was “discovered” in the late 1970’s [28], and has been widely accepted in Europe, as well as elsewhere. Thus there are several European Codes covering TOFD [29, 30].

ASME was somewhat late in producing a TOFD code [3], as these were prepared in Europe first (see ref [28] for example). However, there are some differences between the ASME Code and European one’s. For example, ASME’s primary reference block is the standard ASME Calibration block with side-drilled holes. In contrast, the European codes typically allow one to calibrate on all kinds of different reflectors: lateral wave, standard reference notches, grass level reflections, even a “known” crack (whatever that is). Conveniently TOFD is unique as it can be calibrated after scanning.

The other major difference is ASME’s requirement to use ultrasonics to inspect the root and cap areas – traditionally un-inspectable using TOFD due to the presence of dead zones. Note that this is a reasonable requirement for new construction welds (which ASME is primarily targeting in Section V). ASME also has a TOFD Interpretation Manual [4] and TOFD set-up guidelines [5] published.

**Guided Waves (GW)**

Guided waves are the “new kid on the block”, and are only now getting into codes. There are both a draft ISO GW code and a draft ASME GW code in progress. In terms of actual published documents, ASTM has a SP for guided waves [32]. This ASTM SP is specifically for piezo-electric GW, but another should be available soon covering EMAT-driven GW.
Further Familiarity with Phased Arrays

Olympus NDT runs a Training Academy (see www.olympus-ims.com/training) which operates several hundred courses per year. There are currently 28 training companies involved, spread all around the globe. The web site offers both a description of the company and courses, and a schedule of the course locations [33].

Olympus NDT has published a number of books, with two likely to be the most useful [34, 35]. One is the Intro book, while the other is an in-the-field booklet. Lastly, a paper was presented at the European Conference on NDT in 2006 on some of the limitations of phased arrays – and these should be considered [36]

Conclusions (which of these should be recommendations?)

For phased arrays, ASME dominates, though associated code bodies (e.g. ASTM and API) are also in the group.

ASME has a comprehensive list of Mandatory Appendices in their B&PV Code, covering manual and encoded PA, AUT and others.

AWS is well behind on accepting encoded PA, though recently appears to be catching up.

TOFD is well codified – especially from Europe. ASME has a TOFD Code, as well as a NonMandatory Interpretation Manual and TOFD set-up guidelines.

Guided Waves are relatively new, but are short on codes.

References


Mandatory Appendix V, *idem*, “Phased Array E-scan and S-scan Linear Scanning Examination Techniques”, July 2010

Mandatory Appendix VI, *idem*, “Ultrasonic Examination Requirements for Workmanship Based Acceptance Criteria”, July 2010

Mandatory Appendix VII, *idem*, “Ultrasonic Examination Requirements for Fracture Mechanics Based Acceptance Criteria”, July 2010

Mandatory Appendix VIII, *idem*, “Procedure Qualification Requirements for Flaw Sizing and Categorization”, July 2010


23. See ASTM “Standards on Disc” volume 3.03, [www.astm.org](http://www.astm.org)

24. Total Focusing Method, see for example, [http://www.ndtnews.org/On_The_Job/What_the_Hec!/TFM.html](http://www.ndtnews.org/On_The_Job/What_the_Hec!/TFM.html)

ASME Section V, Article 14, 2010, “Examination System Qualification”.

25. See API Codes, especially RP2X for offshore, 620 tank construction and 1104 for pipeline AUT.


27. Private communication with AWS D1.1 Committee.


BS7706, Guide to calibration and setting-up of the ultrasonic time of flight diffraction (TOFD) technique for the detection, location and sizing of flaws, 1993.

EN 583_6, now replaced by EN14751, “Welding – use of time of flight diffraction technique (TOFD) for examination of welds”, November 2004.


See [http://www.olympus-ims.com/training](http://www.olympus-ims.com/training)


- **Make repair decisions based on fitness-for-service assessments.** Currently many repair decisions are made on workmanship standards, where accept/reject decisions are based on appearance. However unnecessary repairs often introduce additional damage that can be the
source for later failures during service. Switching to repair decisions based on fracture mechanics (quantitative engineering calculations rather than workmanship standards based on appearance) would mean that only necessary repairs are made, and provides a quantitative measure of expected performance, rather than just accept/reject.

(Commentary: Harold Gray is leading this effort, with assistance from Dana Couch. While some of the technical issues are already under consideration in ASME Section III, API 579, AWS D1 .1, and AWS D1 .5, we decided to see what else could be added, and whether the changes are consistent with each other. We decided that the need is greater in new construction then in repair of existing plants. Please send any input to both Tom Siewert and to Harold Gray.)

Text from an e-mail that may form the content for this section.
1. Summary of the problem: Can weld repairs of structurally insignificant RT indications be avoided thru analytic efforts?
2. Inputs: ASME Code Case N-818, 10CFR 50, and 50.55a(g), EPRI Report 1021181
3. Who is working on FFS and what, who are needed? ASME Code subcommittee, EPRI
4. Report for next NESCC meeting to show task request input, see the above and comments
5. Description of issue, application to AWS D1.1 and D1.5, new construction, maintenance / repair,
The interest in FFS is that there have been pipe wall leaks associated with thru wall repairs where a small radiographic (RT) indication was removed, rewelded, passed RT but resulted in a high stress field, susceptible to a higher rate of degradation than the rest of the pressure boundary
6. References: Previous NESCC minutes, Code Case N-818, see ASME 2010 and ASME FFS-1 / API 579

Possible recommendation: (now in the Recommendations Section)

The ASME Code and its member contributors have issued Code Case N-818, “Use of Analytical Evaluation Approach for Acceptance of Full Penetration Butt Welds in Lieu of Weld Repair”, revision 0. Revision 1 is in progress.

The NRC has not endorsed N-818. If a user wanted to apply N-818, they would have to prepare a relief request, send it to NRC and have it approved, otherwise they would not be in a position of meeting 10CFR55a(g)

Comments:

A. One problem with CC N-818 is with the UT personnel qualification process is having construction indications present in the PDI test assemblies, adequate for PDI purposes. In summary, the FFS development in ASME is in progress. When they complete it, then NRC will
evaluate it for possible inclusion in the NRC acceptable list of ASME Code Sections and N Code Cases. Details of other questions are with that Code subcommittee.

B. In the ASME Section XI, In-Service Inspection (ISI), fitness for service via evaluation of indications is a current means of indication acceptance, with follow-up inspections to verify the adequacy of the assumptions being required.

C. One of the action items in the NESCC Task group is to consider is the fitness for service (FFS) applications for nuclear construction and possible application to repair and replacement at operating plants.

D. The safety interest in FFS is that there have been pipe and SG vessel wall leaks associated with thru wall repairs where a small radiographic (RT) indication was removed, rewelded, passed RT but resulted in a high stress field, susceptible to a higher rate of degradation than the rest of the pressure boundary.

Send comments on this section to Harold Gray,

610-337-5325
Recommendations

- **Develop a liaison between the AWS B2 committee (which feeds into ASME Section IX) and AWS D1.1 committee** so their welding procedures could be as similar as possible, or ideally, identical.

- **Develop new standardized welding procedures and expand the scope of existing ones**, so that individual and procedures do not need to be developed by each company. This might be funded by having the AWS B2 committee (which feeds into ASME Section IX) and AWS D1.1 committee develop a proposal to the ASME Foundation (which funds research to make the application of their code more efficient).

- **Make more repair decisions based on fitness-for-service assessments.** Currently many repair decisions are made on workmanship standards; however, cosmetic repairs (those that have no effect on the service life or performance) often introduce additional damage that can be the source for later failures during service. Switching to repair decisions based on the fracture mechanics would mean that only necessary repairs are made.
Appendices

Appendix 1. Comparison of ASME B to and ASME section IX requirements (being prepared by Jeff Fluckiger)