TRANSNET ENGINEERING

PRODUCT SYSTEMS DEVELOPMENT

WELDING COMPLIANCE

NDT

Phased Array Examination of Welds

E-scan and S-scan linear scanning

Revision 00

Date of Release:

13 February 2024

SUMMARY OF REVISION

First issued – 13 February 2024

Document No. TBA

The following revisions have been made in this revision:

Change	Description
00	Preliminary Specification

0.2. Table of contents

1.1 Scope of Specification

1.0. Purpose

a) The purpose of this specification is to outline the Phased Array examination requirements and the method specific examination E-scan and S-scan thereof employed by Transnet Engineering SOC.

2.0. Scope

a) This work instruction describes general requirements to be used for Manual, Automated or Semi-automated phased array encoded E-scan (fixed angle), S-scan (sweeping multiple angle) and L-scan (fixed angle) using linear array search units.

b) This work instruction covers butt welds in plate and pipe, for ferrous material thickness ranges between 9mm to 200mm, other metallic material or Greater/lesser thickness may be tested if the technique can be demonstrated to provide adequate detection on mockup of the same Material, wall thickness and geometry.

c) The requirements of this work instruction, as a minimum, comply with ASME V Article 4 & Table V-421.

d) When qualification of this written instruction is specified, a change of requirement in Table V-421 (Appendix I) identified as essential variable for specific value, or range of values shall require requalification of this work instruction and validation of the technique.

e) All changes of essential or nonessential variables from the value, or range of values specified shall require revision, or an addendum/technique sheet to, this work instruction.

f) This is a general work instruction and shall be used in conjunction with specific technique sheet [to be attached to or part of the examination report].

3.0. Reference documents

a) The following documents are incorporated into this work instruction by reference in later paragraphs, unless otherwise specified when referenced; they form a part of this work instruction in their entirety. Where reference is made, the reference shall be taken to imply the latest edition and as agreed and specified in the relevant purchase order.

b) For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

Reference	Description
ISO 9001	Quality Systems –Requirements.
DS 01	De-Tect Unit Inspection Written Practice.
SS 08PAUT	Characterization and verification of ultrasonic phased array equipment - combined systems
ASME I	Rules for Construction of Power Boilers.
ASME V Art. 1	General requirements.
ASME V Art. 4	Ultrasonic Examination of Welds.
ASME V Art. 23	Ultrasonic Standard.
ASME VIII Div. 1	Rules for Construction of Pressure Vessels.
ASME VIII Div.2	Rules for Construction of Pressure Vessels - Alternative Rules.
ASME VIII Div.3	Alternative Rules for Construction of High-Pressure Vessels.
ASME B31.1	Power Piping.
ASME B31.3	Process Piping.
ASME IX	Welding and Brazing Qualifications.

4.0. Definitions and abbreviations

Abbreviation	Description
NDT	Non-destructive Testing.

Phased Array	A method of producing multiple probe angles and wave forms from a single probe containing multiple elements fired in discrete sequences.
TCG	Time Corrected Gain.
SDH	Side Drilled Whole.
M/S PA	Manual/Semi-automated phased array testing.
PAUT	Phased Array Ultrasonic Testing.
ASL	Approved Suppliers List.
FSH	Full Screen Height.
PRL	Primary reference Level.
ACG	Angle corrected gain. This is compensation for the variation in signal amplitudes received from fixed depth from side-drilled holes (SDHs) during S-scan calibration. The compensation is typically performed electronically at multiple depths.
Linear array probe	Probes made using a set of elements juxtaposed and aligned along a linear axis. They enable a beam to be moved, focused, and deflected along a single azimuthal plane.
Gate	The gated section of the ultrasonic beams travel where the data is collected and recorded.
Focal law	The entire set of hardware and software parameters affecting the acoustic sensitivity field of a phased-array search unit, whether a pulse-echo or a pitch-catch configuration. Within focal laws, there are included delay laws in transmitter and delay laws in receiver, as well as apodization laws, and element activation laws.
L-scan	Termed as Linear scan, is a focal law applied to a specific set of active elements for a constant angle beam, emulating a conventional single element probe.
E-scan	Termed as an electronic raster scan, is a single focal law multiplexed, across a grouping of active elements, for a constant angle beam stepped along the phased array probe length in defined incremental steps.
S-scan	Termed as Sector, Sectorial, or Azimuthal scan, may refer to either the beam movement or the data display.

	(a) Beam movement is the set of focal laws that provides a fan-like series of beams through a defined range of angles using the same set of elements. (b) Data display is the two-dimensional view of all A-scans from a specific set of elements corrected for delay and refracted angle. Volume-corrected S-scan images typically show a pie-shaped display with defects located at their geometrically correct and measurable positions.
Ferrous	Adjective used to indicate the presence of iron. The word is derived from the Latin word ferrum ("iron"). Ferrous metals include steel and pig iron (with a carbon content of a few percent) and alloys of iron with other metals (such as stainless steel).
Workmanship based Acceptance criteria	Is defined as a standard for acceptance of a weld based on the characterization of imperfections by type (i.e., crack, incomplete fusion, incomplete penetration, or inclusion) and their size (i.e., length).
Fracture mechanics-based Acceptance criteria	Is defined as a standard for acceptance of a weld based on the categorization of imperfections by type (i.e., surface or subsurface) and their size (i.e., length and through-wall height).

5.0. Personnel qualification, responsibilities & authorities

a) Personnel shall be qualified, certified, and authorized in accordance with Transnet Engineering written practice and as per referencing code section and/or client specification.
b) It is the responsibility of the Transnet Engineering level III to ensure that only qualified and certified personnel are authorized.
c) PAUT Level II/III are responsible for creating the setup file and compiling a job specific Technique Sheet.
d) Only PAUT Level II/III has the authority to report/evaluate [accept or reject] the results of the test.

e) UT Level I/II personnel may provide assistance in data collection under supervision of a Level II/III PAUT technician.

6.0. Equipment

6.1 Phased Array Instruments

a) The ultrasonic phased array instrument shall be a pulse echo type and shall be equipped with a standardized dB gain or attenuation control stepped in increments of 1 dB minimum, containing multiple independent pulser/receiver channels. The system shall be capable of generating and displaying both B-scan and S-scan images, which can be stored and recalled for subsequent review.
b) The phased array system shall have on-board focal law generation software that permits direct modification to ultrasonic beam characteristics. Specific delay calculations may be performed by the system itself or imported from external calculations.
c) The phased array system shall have a means of data storage for archiving scan data. An external storage device, flash card or USB memory stick can be used for data storage. A remote portable PC connected to the instrument may also be used for this purpose. If instruments do not inherently store A-scan data, such as some manual instruments, the final image only may be recorded.
d) The phased array system shall be standardized for amplitude and height linearity in accordance with E2491.
e) The instrument shall be capable of pulsing and receiving at nominal frequencies of 1 MHz to 10 MHz For special applications, frequencies up to 20 MHz can be used, but may require special instrumentation with appropriate digitization, and special approval.
f) The instrument shall be capable of digitization of A-scans at a minimum of five times the nominal frequency of the probe used. Amplitude shall be digitized at a resolution of at least 8-bit (that is, 256 levels).
g) The instrument shall be capable of equalizing the amplitude response from a target at a fixed sound path for each angle used in the technique (angle corrected gain (ACG) thereby providing compensation for wedge attenuation variation and echo-transmittance).
h) The instrument shall also be equipped with facilities to equalize amplitudes of signals across the time-base (time-corrected gain).

6.2 Phased Array Probes

a) The application requirements will dictate the design of the phased array probe used. Phased array probes may be used with a removable or integral wedge, delay-line, or in an immersion or localized bubbler system mode. In some cases a phased array probe may be used without a refracting wedge or delay-line (that is, just a hard wear-face surface).
b) The number of elements in the phased array probe and the element dimensions and pitch shall be selected based on the application requirements and the manufacturer's recommended limitations.
c) The probe selected shall have elements that are addressable by the pulser-receivers available in the phased array instrument being used.
d) When refracting wedges are used to assist beam steering, the natural incident angle of the wedge shall be selected such that the angular sweep range of the examination technique used does not exceed the manufacturer's recommended limits for the probe and mode (compression or transverse) used.
e) Refracting wedges used on curved surfaces shall require contouring to match the surface curvature if the curvature causes a gap between the wedge and examination surface exceeding 0.5 mm (0.020 in.) at any point.

6.3 Couplant

a) A couplant, usually a liquid or semi-liquid, is required between the face of the search unit and the surface to permit transmission of the acoustic energy from the search unit to the material under examination. The couplant should wet the surfaces of the search unit and the test piece and eliminate any air space between the two. Typical couplants include water, oil, grease, glycerin, and cellulose gum. The couplant used should not be injurious to the material to be examined, should form a thin film, and, with the exception of water, should be used sparingly. When glycerin is used, a small amount of wetting agent is often added, to improve the coupling properties. When water is used, it should be clean and de-aerated if possible. Inhibitors or wetting agents, or both, may be used.

b) The coupling medium should be selected so that its viscosity is appropriate for the surface finish of the material to be examined.

c) For contact examination, the temperature differential between the reference block and examination surface shall be within 14°C (25°F).

d) Couplants used on austenitic stainless steels shall contain no more than 250 ppm of halides.

e) The same couplant to be used during examination shall be used for calibration.

6.4 Calibration blocks

a) The following calibration blocks shall be available.

- IIW VI Calibration Block
- IIW V2 Calibration Block
- Calibration block(s) with specified reflectors covering the material, radii, and thicknesses over which subsequent testing will be conducted. (Figures 1 and 2)

b) Reflectors

Side drilled holes, flat bottom holes or notches shall be used to establish primary reference responses of the equipment.

c) Material

- Similar metals welds. The material from which the calibration blocks are fabricated shall be of the same product form and material specification or equivalent P-Number grouping as one of the materials being examined. P-Nos. 1, 3, 4, 5A through 5C, and 15A through 15F are considered equivalent.
- Dissimilar metals welds. The material selection shall be based on the material on the side of the weld from which examination will be conducted. If the examination will be conducted from both sides, calibration reflectors shall be provided in both materials.

d) Quality

Prior to fabrication, the block material shall be completely examined with a straight beam transducer to establish any interference with the purpose of the block.

e) Cladding

When the component material is clad, the block shall be clad by the same method as used on the production part, the thickness of the clad shall be + 3mm to the production part. Deposition of clad shall be by the same method as used to clad the component to be examined, when the method of cladding is unknown or the method of cladding used on the component is not practical for block cladding, deposition of cladding may be by the manual method.

f) Heat Treatment

The calibration block shall receive at least the minimum tempering treatment required by the material specification for the type and grade.

g) Surface finish

The finish of the scanning surfaces of the block shall be representative of the scanning surface finishes on the component to be examined.

h) Block Curvature

I. Materials with diameters greater than 500mm

For examination in materials where the examination surface diameter is greater than 500mm, a flat basic calibration block may be used.

II. Materials with diameters less than 500mm

For examination in materials where the examination surface diameter is less than 500 mm, a curved block shall be used. A single curved block may be used for examinations in the range of curvature from 0.9 to 1.5 times the basic calibration block diameter. For example, a 200mm diameter block may be used to calibrate for examinations on surfaces in the range of curvature from 180mm to 300mm in diameter.

i) Non-Piping Calibration Blocks

The basic calibration block configuration and reflectors shall be as in Figure 1. The block size, and reflector locations shall be adequate to perform calibrations for the beam angles used. When the block thickness (25mm) spans two weld thickness ranges as shown in Figure 1, the block's use shall be acceptable in those portions of each thickness range covered by

(25mm) of the calibration block's thickness. For example, a calibration block with a thickness of 38mm could be used for weld thicknesses of 13mm to 63mm.

j) Piping Calibration Blocks

The basic calibration block configuration and reflectors shall be as shown in *Fig 2.* The basic calibration block curvature shall be in accordance with paragraph 8 (h). Thickness, T, shall be within 25% of the nominal thickness of the component to be examined.

The block size, and reflector locations shall be adequate to perform calibrations for the beam angle(s) and distance range(s) to be used.

7.0. Calibration

7.1 Set up file

a) A scan set-up file will be required for each weld thickness and weld configuration and shall be noted in the technique sheet or be part of the examination report.

b) During set-up, the details of the material thickness, weld preparation angles and gate size are input into the computer program. This is together with required information on the probe type, distance separation, material velocity etc. When all the data has been input into the PA unit software program, the setup file can then be saved for future use.

7.2 Range Calibration

a) The instrument display shall be adjusted using the A-scans for each focal law used to provide an accurate indication of sound travel in the test material. Range standardization shall include correction for wedge travel time so that the zero-depth position in the test piece is accurately indicated for each focal law.

b) Volume-corrected B-scan, C-scan or D-scan displays [figure 4] shall indicate the true depth to known targets to within 5% of the physical depth or 3 mm, whichever is less.

c) Range standardization shall be established using the radius surfaces in reference blocks such as the IIW V1 Block and these blocks shall be made of the same material or acoustically similar material as the test piece.

7.3 Sensitivity Calibration

a) Reference standards for sensitivity-amplitude calibration should be designed so that sensitivity does not vary with beam angle when angle beam testing is used.

b) Sensitivity amplitude reference standards that accomplish this are side-drilled holes parallel to the major surfaces of the plate and perpendicular to the sound path, flat-bottomed holes drilled at the testing angle, and equal-radius reflectors. Surface notches may be used under some circumstances but are not generally recommended.

c) Calibration shall include the complete ultrasonic phased array system and shall be performed prior to use of the system in the thickness range under examination.

d) Calibration on reference block(s) shall be performed from the surface (clad or unclad, convex, or concave) corresponding to the surface of the component from which the examination will be performed.

e) The same contact wedges or immersion/bubbler systems used during the examination shall be used for calibration.

f) The same focal law(s) used in calibration shall be used for examination.

g) Any control which affects instrument amplitude response (for example, pulse-duration, filters, averaging, etc.) shall be in the same position for calibration and examination.

h) Any control which affects instrument linearity (for example, clipping, reject, suppression) shall not be used.

7.4 Focal Law Calibration

The focal law to be used during the examination shall be used for calibration.

7.5 Beam Calibration

All ultrasonic beams used in the examination shall be calibrated to provide measurement of DAC/TCG over the sound path employed in the examination.

7.6 TCG Calibration

a) Side-drilled holes used as targets in this document should have diameters more than the wavelength of the pulse being assessed and long enough to avoid end effects from causing interfering signals. This will typically be accomplished when the hole diameter is between about 1.5 mm and 2.5 mm and 20 mm to 25 mm in length.

b) With the instrument display in time or sound path (not true depth) locate the focal law that provides the maximum response from the reference targets. Set the signal from the reference reflector that gives the highest response, to a screen height of between 40% to 80% full screen height (FSH). This target may be considered the primary reference reflector.

c) Using the same focal law, maximize each of the other reference reflectors at other distances over the range to be used for examination, adjusting the electronic distance amplitude correction controls to equalize the screen height from these reference reflectors to the primary reflector. Apply the correction to all focal laws used for the examination.

d) Other methods of accomplishing the equalization of amplitude for all focal laws used from equal-size reflectors over the examination distance range may be used.

The method for the system used is best described for each instrument in the operating manual for that instrument.

7.7 Encoder Calibration

a) A calibration check shall be performed every day/shift, prior to commencement of any job, by moving the encoder a minimum distance of 20 in. (500 mm). The display distance shall be within 1% of the actual distance moved.

7.8 Transfer Correction

a. When the block material is not of the same product form or has not received the same heat treatment, it may be used provided it meets all other block requirements and transfer correction for acoustical property deference between the signal response, using the same transducer and wedges to be used in the examination, received from either;

1. The correspondence reference reflector (same type and dimensions) in the basic calibration block and in the component to be examined, or

2. Two search units positioned in the same orientation on the basic calibration block and component to be examined (see Figure 3).

b. Transfer correction values should be determined initially before examination.

c. Any deference more than + 2 dB, shall be added to the Primary Reference Level.

7.9 Calibration confirmation

a) When any part of the examination system is changed, a calibration check must be made on the basic calibration block(s) to verify that range points or sensitivity setting(s) are maintained. Changes made must be documented on the calibration sheet before proceeding with the examination.

b) Any distance range points has moved on the sweep line by more than 10% of the distance reading; or 5% of full sweep (range); and/or the sensitivity setting has changed by more than 20% or 2 dB in amplitude will result in the re-examination of all components since the last valid calibration or calibration check and the data changed or re-recorded.

7.10 Calibration documentation

a) All calibration checks shall be recorded on standard calibration sheet.

8.0. Surface preparation

a) The surfaces on which the examination is to be performed shall be free from scale, weld spatter, or any matter that could interfere with the free movement of the search unit or impair the transmission of ultrasound into the test specimen.

b) Where the above condition cannot be met, the contact surface may be prepared by manual or mechanical suitable process approved by the client. Care should be taken that preparation of the surfaces does not reduce material thickness outside the specified limits.

c) Where the weld is not flat and flush with the adjacent materials, the weld cap is recorded as an examination limitation.

d) Any surface on which scanning cannot be performed shall be regarded as a limitation and it shall be recorded on the relevant report as such. A sketch showing the limitations relevant to the weld and the length of the limitation relevant to the zero-datum mark is required.

e) The surfaces temperature of the weld or plate under examination will generally be in the range of 0° to 50°. Higher temperatures can be tested with specific couplant and after a positive result from the demonstration.

f) The temperature differential between the calibration block and examination surfaces shall be within (14°C).

9.0. Identification of weld examination areas

a) Weld locations

Weld locations and their identifications shall be recorded on a weld map or an identification plan.

b) Marking

If welds are to be permanently marked, low stress stamps, and/or vibrate tooling may be used. Markings applied after final stress relief of the component shall not be any deeper than 1.2 mm.

c) Reference System

Each weld shall be located and identified by a system of reference points. The system shall permit identification of each weld center line and designation of regular interval along the length of the weld. These requirements shall be strictly adhered to as this provides the basis for further inspection i.e. monitoring of indications, propagation of cracks etc.

d) Scan plan

I. A scan plan shall be developed. The scan plan, in combination with the written procedure, shall address all requirements of Table IV-421.

II. Documented examination strategy shall be provided showing search unit placement and movement that provides a standardized and repeatable methodology for the examination. In addition to the information in

Table V-421 [APPENDIX I], the scan plan shall include beam angles and directions with respect to the weld axis reference point, weld joint geometry, and number of examination areas or zones [Scan plane shall be on the PAUT report form or specific technique sheet].

III. The examination angle(s) for E-scan/L-scan and range of angles for S-scan shall be appropriate for the joint to be examined.

IV. Scanning speed shall be such that data drop-out is less than 2% data lines of the linear scan length and that there are no adjacent data line skips.

V. For E-scan techniques, overlap between adjacent active apertures (i.e., aperture incremental change) shall be a minimum of 50% of the effective aperture height.

VI. For S-scan techniques, the angular sweep incremental change shall be a maximum of 1º or sufficient to assure 50% beam overlap.

VII. When multiple scans are required to cover the required volume of weld and base material, overlap between adjacent scans shall be a minimum of 10% of the effective aperture height for L-scans or beam width for S-scans.

10.0. Examination

a) **Examination Coverage**

I. The required volume of the weld and base material to be examined shall be scanned using one or more S-scan and/or L-scan technique to cover the entire area of interest as applicable.

II. Scan shall be parallel to the weld axis at a constant standoff distance with the beam-oriented perpendicular to the weld axis.

III. The search unit shall be maintained at a fixed distance from the weld axis by a fixed guide [e.g., magnet strip] or mechanical means.

b) **Parent Metal Examination**

I. The area both sides of the weld up to where phased array wedge's end will + 50mm shall be examined with a compression wave probe, to detect any laminations or inclusions that could interfere with the subsequent angle beam inspection.

II. A thickness survey shall be conducted to confirm wall thickness measurements on base metal next to weld segment to aid plotting when working beyond half skip distances for S-scan and/or L-scan.

c) **Transverse Defects**

Reflectors transverse to the weld seam, as an alternate to line scanning, a manual angle beam examination may be performed for reflectors transverse to the weld axis.

d) **Single-sided Access Weld**

Welds that cannot be fully examined from two direction using angle beam technique shall also be examined to the maximum extent possible with a straight beam technique applied from an adjacent base material surface. These areas of restricted access shall be noted in the examination report.

e) **Inaccessible Welds**

Welds that cannot be examined from at least one side (edge) using the angle beam technique shall be noted in the examination report. For flange welds, the weld may be examined with a straight beam or low angle longitudinal waves from the flange face provided the examination volume can be covered [Convention UT examination method may be used].

f) **Examination Strategy**

Prior to an inspection, the index offset needs to be established which will accommodate an inspection that will ensure 100% coverage of the weld and to include the HAZ. An overlay shall be produced with the exit points from each group plotted out and placed over a mock-up weld profile or if possible an actual weld profile. The distance from the centerline of the weld to the front of the probe will be the index offset position and shall be used for the inspection.

NOTE:

1. Index offset will change for each different thickness and weld configuration.
2. Generally using more focal laws requires more processing time so update rates of the B-scan or S-scan displays are slower as more focal laws are used.

11.0. Interpretation and sizing of indication(s)

INTERPRETATION:

a) PAUT data is routinely displayed using a rainbow color palette, with the range of colors representing a predetermined color pallet a range of signal amplitude. Generally, “white” represents 0% signal amplitude, e.g., “blue” (or lighter colors) represents low amplitudes, and “red” (or darker colors) represents above reject signal.

b) PAUT has the ability to image the data in the same format as conventional ultrasonics’ – A-scans, and time or distance encoded B-scan, D-scan, and C-scans.

c) The PAUT primary image displays are an E-scan or S-scan, exclusive to the PAUT technique. Both the E-scan and S-scan display the data in a 2D view, with distance from the front of the wedge on the X-axis, and depth on the Y-axis. This view is also considered an end view." E-scans and S-scans are composed of all the A-scans (or focal laws) in a particular setup. The A-scan for each beam (or focal law) is available for use in flaw signal interpretation.

d) Indications must be classified as either geometric or flaw indications.

e) Geometric indications are indications which are determined to originate from surface conditions such as root geometry i.e. counter boring, root profile etc. The identity, maximum amplitude, location and extent of the reflector causing a geometric indication shall be recorded. The following steps are to be taken to classify and indication as geometric; I. Interpret the area containing the reflector in accordance with the applicable technique sheet.

II. Plot and verify the reflector co-ordinates on a cross-sectional sketch showing the reflector position and the surface discontinuities such as root and/or counter bore.

III. Review fabrication or weld detail drawings and discuss fit-up anomalies with manufacturer if necessary to confirm origin of reflectors.

IV. Other Ultrasonic Techniques or non-destructive methods may be helpful in confirming a reflector true origin, position, size and orientation.

NOTE:

ASME V [2017], Article 4, Non-mandatory Appendix P [phased array (PAUT) interpretation] paragraph P-480, shows a variety of PAUT images and the interpretation/explanation and should be used as a guide only.

SIZING TECHNIQUES:

a) Flaw sizing can be performed using a variety of industry accepted techniques, such as amplitude drop (e.g., -6 dB Drop) techniques and/or tip diffraction techniques. Different flaw types may require different sizing techniques.

b) Flaw Length.

➢ Flaw lengths parallel to the weld excess can be measured from the distance encoded B- or C-scan images using amplitude drop techniques by placing the vertical cursors on the extents of the flaw displayed on the B- or C-scan display.

➢ Indication length is generally determined by determining the distance between the points along the weld length where the amplitude drops to half the maximum at the extremities of the reflector, or when the amplitude drops to half the minimum evaluation amplitude.

➢ Estimates of indication height can be made using the 6-dB drop as determined from the S-scan or B-scan. This method is suitable for large planar flaws with extents greater than the beam. For flaws with dimensions smaller than the beam a correction for beam divergence may be used to improve sizing estimates. For adversely oriented indications or indications with irregular surfaces, amplitude sizing techniques may not accurately indicate size or severity of the indications.

c) Flaw Height. Flaw height normal to the surface can be measured from the B-, E-, or S-scan images using amplitude drop or tip diffraction techniques.

I. Using amplitude drop techniques, the horizontal cursors are placed on the displayed flaws upper and lower extents.

II. Using tip diffraction techniques the horizontal cursors are placed on the upper and lower tip signals of the displayed flaw.

d) Size and Category for Fracture Mechanics Based acceptance criteria [ASME V, Article 4, Mandatory Appendix VIII]

I. Size. The dimensions of the flaw shall be determined by the rectangle that fully contains the area of the flaw.(a) The length of the flaw shall be the dimension of the rectangle that is parallel to the inside pressure-retaining surface of the component.

II. Height. The height of the flaw shall be the dimension of the rectangle that is normal to the inside pressure-retaining surface of the component.

III. Category. Flaws shall be categorized as being surface or subsurface based on their separation distance from the nearest component surface.

➢ If the space is equal to or less than one-half the height of the flaw, then the flaw shall be categorized as a surface flaw [A flaw need not be surface breaking to be categorized as a surface flaw].

➢ If the space is greater than one-half the height of the flaw, then the flaw shall be categorized as a subsurface flaw.

12.0. Recording level

a) A-scan data shall be recorded for the area of interest in an unprocessed form with no thresholding, at a minimum digitization rate of five times the examination frequency, and recording increments of a maximum of:

➢ 0.04 in. (1 mm) for material < 3 in. (75 mm) thick

➢ 0.08 in. (2 mm) for material ≥ 3 in. (75 mm) thick

b) **Base Metal (Compression Probe)**

➢ Record all indications (rejectable or non-rejectable) with echo amplitudes equal to or greater than 50% of the initial back reflection and accompanied by a 50% loss of back wall reflection.

➢ Record any areas where a 6dB or greater attenuations of the back wall echo occur. The possible cause of such attenuation should be further investigated.

c) **Weld Examination [S-scan and L-scan]**

➢ All imperfection that produce echo amplitudes greater than 20% of the reference level shall be investigated to the extent that the operator can determine the shape, identity and location of all such imperfections, and evaluate them in terms of the acceptance standard of the Contract Requirements.

➢ All indications (rejectable or non-rejectable) produce echo amplitudes greater than 50% of the reference level shall be recorded on standard PAUT report form.

13.0. Evaluation

a) Evaluation of all relevant indications will be made against the acceptance criteria agreed upon by the contracting parties.

b) Flaws detected during the automated or semi-automated scan may be alternatively evaluated, if applicable, by supplemental manual techniques.

c) For manual scanning using phased arrays examination personnel shall use a real-time S-scan or B-scan display during scanning to monitor for coupling quality and signals exceeding the evaluation threshold.

d) Evaluation of indications detected using manual phased array methods shall require the operator to assess all indications exceeding the evaluation threshold when the indication is detected during the scanning process.

e) Some phased array systems may include options for entering some items into a report format and incorporating S-scan or B-scan images as part of the report.

f) Evaluation of indications detected by encoded phased array scanning shall be made using the digitized waveforms underlying the S-scans or B-scans collected during the data acquisition process.

g) Encoded scanning data displays for indication evaluation may use a variety of projections other than just the S-scans or B-scans available to manual scanning (for example, top-side-end views).

h) Welds scanned using encoded techniques may be scanned in sections provided that there is an overlap of data collected and the overlap between scans is identified in the encoded position with respect to the weld reference start position (for example, a 2-m long weld may be scanned in two parts; one from 0 mm to 1 000 mm and the second from 950 mm to 2 000 mm).

i) The evaluation threshold should be indicated on the S-scan or B-scan display as a well-defined color such that indications of note are easily distinguished from the background level.

j) S-scan or B-scan images presented with angular correction (also referred to as volume corrected) contain signal amplitude and indication depth information projected for the refracted angle of the ultrasonic beam.

k) Indication locations shall be determined relative to the inspection surface and a coordinate system that uses well defined reference for the relative to the weld.

l) Reflectors evaluated as laminar reflectors in the base material which interfere with the scanning of the examination volume shall require the scan plan to be modified such that the maximum feasible volume is examined and shall be noted in the record of the examination.

14.0. Acceptance criteria

a) Acceptance and rejection shall be as per referencing code section, client specification and/or by agreement.

b) Acceptance criteria shall be stated on job request and PAUT report form.

15.0. Re-inspection

a) Re-inspection of welds, after repairs if required, will be carried out using the same technique and parameters that were used for the original inspection.

b) An additional 50mm will be added on both sides of the area of the repair area to ensure coverage of this area in question.

16.0. Documentation

a) **Data recording**

I. Data, in the form of A-scans from each focal law used, shall be collected at increments of not greater than 2 mm (with at least three increments for the length of the smallest required detectable defect, that is, a defect length of 3 mm would require increments of not greater than 1 mm) along the scan axis. Note that this interval should be reduced when length sizing of flaws is critical with respect to the acceptance criteria.

II. If laterally focused beams are used, this can be considered for data collection increments as above.

III. Data is recorded in unprocessed form. A complete data set with no gating, filtering, or thresholding for response from examination volume shall be included in the data record.

b) **Recording indications**

I. ***Nonrejectable Indications:*** Non-rejectable indications shall be recorded as specified by the referencing Code Section.

II. ***Rejectable Indications***: Rejectable indications shall be recorded. As a minimum, the type of indication (i.e., crack, non-fusion, slag, etc.), location, and extent (i.e., length) shall be recorded. a) Couplant used.

17.0. Examination report

The results of the PAUT carried out shall be recorded on standard Report Form including the following as a minimum.

a) Couplant used.

b) Calibration data.

c) Beam angles used.

d) Date of examination.

e) Simulation blocks used.

f) Areas of restricted access.

g) Instrument reference level gain.

h) Identification and location of weld.

i) Calibration blocks used and identification.

j) Search units' identification and serial numbers.

k) Surface from which examination was conducted.

l) Phased array ultrasonic instrument identification and serial number.

m) Map of rejectable and non-rejectable recordable indications detected.

n) Procedure, technique sheet, acceptance codes and standards used.

o) Operator name, signature, date of inspection and NDT supplier's authorization counter signature.

p) Encoder(s).

q) Angular range of S-scan,

r) Scanning mechanisms used.

s) Scan surfaces and surface conditions.

t) Search unit cables used, type and length.

u) Documented calibration, TCG, and angle gain compensation.

v) Search unit element size, number, and pitch and gap dimensions.

w) Virtual aperture use, that is, number of elements and element width.

x) Documentation on recommended wedge angular range from manufacturer.

y) Method of sensitivity standardization and details of correlating indications with flaws.

z) Focal law parameters, including, as applicable, angle or angular range, focal depth and plane, element numbers used, angular or element incremental change, and start and stop element numbers.

aa) Weld details including thickness dimensions, material, weld process and bevel shape. Descriptive sketches are usually recommended.

bb) Scan plan (indicating probe position on test piece, probe movement, angles used and volume coverage).

cc) Mode of transmission (compression, shear, pulse echo, tandem, through transmission).

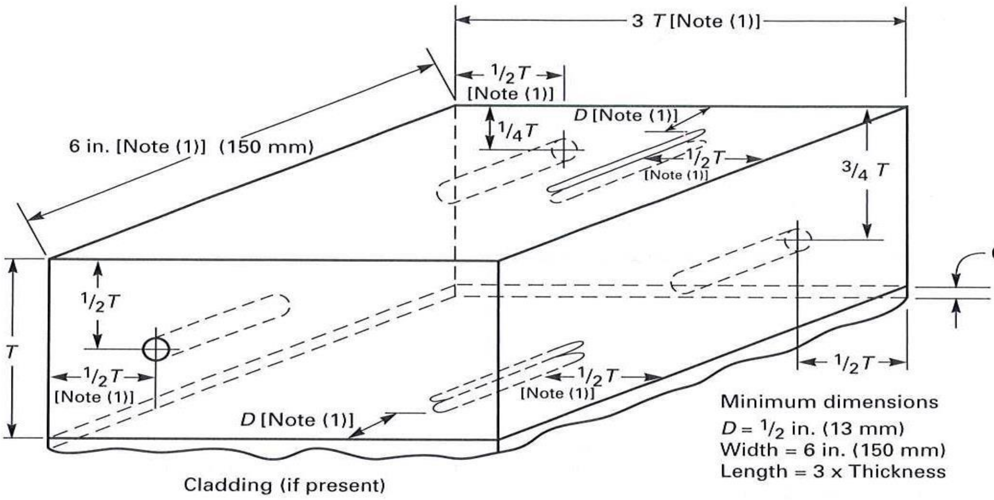
dd) Scanning results (flaw details such as length, position, height, amplitude, acceptability with respect to agreed specifications).

NOTE:

Items (p) through (dd) may be included in a separate record(s) provided the record(s) identification(s) is included in the examination record.

18.0. Figures

Figure T-434.2.1
Non-Piping Calibration Blocks



Notch Dimensions, in. (mm)
Notch depth = 1.6% T to 2.2% T
Notch width = $\frac{1}{4}$ (6) max.
Notch length = 1 (25) min.

Weld Thickness (t), in. (mm)	Calibration Block Thickness (T), in. (mm)	Hole Diameter, in. (mm)
Up to 1 (25)	$\frac{3}{4}$ (19) or t	$\frac{3}{32}$ (2.5)
Over 1 (25) through 2 (50)	$1\frac{1}{2}$ (38) or t	$\frac{1}{8}$ (3)
Over 2 (50) through 4 (100)	3 (75) or t	$\frac{3}{16}$ (5)
Over 4 (100)	t ±1 (25)	[Note (2)]

GENERAL NOTES:

(a) Holes shall be drilled and reamed 1.5 in. (38 mm) deep minimum, essentially parallel to the examination surface.

(b) For components equal to or less than 20 in. (500 mm) in diameter, calibration block diameter shall meet the requirements of T-434.1.7.2. Two sets of calibration reflectors (holes, notches) oriented 90 deg from each other shall be used. Alternatively, two curved calibration blocks may be used.

(c) The tolerance for hole diameter shall be $\pm\frac{1}{32}$ in. (0.8 mm). The tolerance for hole location through the calibration block thickness (i.e., distance from the examination surface) shall be $\pm\frac{1}{8}$ in. (3 mm).

(d) For blocks less than $\frac{3}{4}$ in. (19 mm) in thickness, only the $\frac{1}{2}T$ side-drilled hole and surface notches are required.

(e) All holes may be located on the same face (side) of the calibration block, provided care is exercised to locate all the reflectors (holes, notches) to prevent one reflector from affecting the indication from another reflector during calibration. Notches may also be in the same plane as the inline holes (see Nonmandatory Appendix J, Figure J-431). As in Figure J-431, a sufficient number of holes shall be provided for both angle and straight beam calibrations at the $\frac{1}{4}T$, $\frac{1}{2}T$, and $\frac{3}{4}T$ depths.

(f) When cladding is present, notch depth on the cladding side of the block shall be increased by the cladding thickness, CT (i.e., 1.6% T + CT minimum to 2.2% T + CT maximum).

(g) Maximum notch width is not critical. Notches may be made by EDM or with end mills up to $\frac{1}{4}$ in. (6.4 mm) in diameter.

(h) Weld thickness, t, is the nominal material thickness for welds without reinforcement or, for welds with reinforcement, the nominal material thickness plus the estimated weld reinforcement not to exceed the maximum permitted by the referencing Code Section. When two or more base material thicknesses are involved, the calibration block thickness, T, shall be determined by the average thickness of the weld; alternatively, a calibration block based on the greater base material thickness may be used provided the reference reflector size is based upon the average weld thickness.

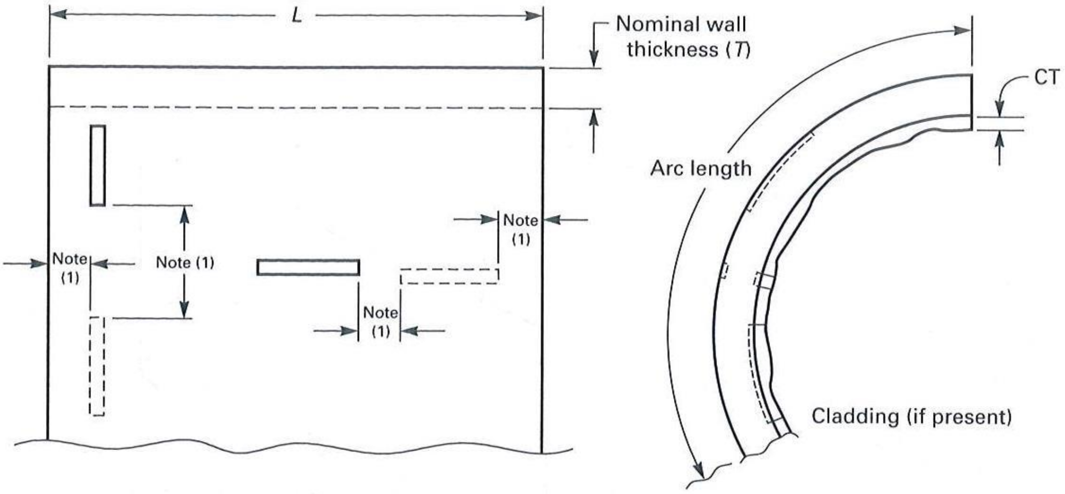
NOTES:

(1) Minimum dimension.

(2) For each increase in weld thickness of 2 in. (50 mm) or fraction thereof over 4 in. (100 mm), the hole diameter shall increase $\frac{1}{16}$ in. (1.5 mm).

Figure 1: Non-Piping Calibration Blocks

Figure T-434.3-1
Calibration Block for Piping



GENERAL NOTES:

(a) The minimum calibration block length, L, shall be 8 in. (200 mm) or $8T$, whichever is greater.

(b) For O.D. 4 in. (100 mm) or less, the minimum arc length shall be 75% of the circumference. For O.D. greater than 4 in. (100 mm), the minimum arc length shall be 8 in. (200 mm) or $3T$, whichever is greater.

(c) Notch depths shall be from 8% T minimum to 11% T maximum. When cladding is present, notch depths on the cladding side of the block shall be increased by the cladding thickness, CT (i.e., 8% T + CT minimum to 11% T + CT maximum). Notch widths shall be $\frac{1}{4}$ in. (6 mm) maximum. Notch lengths shall be 1 in. (25 mm) minimum.

(d) Maximum notch width is not critical. Notches may be made with EDM or with end mills up to $\frac{1}{4}$ in. (6 mm) in diameter.

(e) Notch lengths shall be sufficient to provide for calibration with a minimum 3 to 1 signal-to-noise ratio.

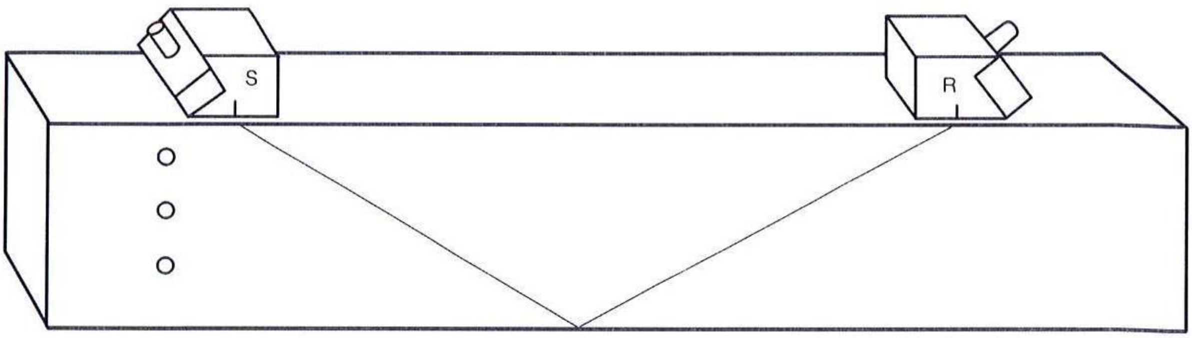
(f) Two blocks shall be used when a weld joining two different thicknesses of material is examined and a single block does not satisfy the requirements of T-434.3.

(g) When a flat block is used as permitted by T-434.1.7.1, the two axial notches may be omitted and the block width may be reduced to 4 in. (100 mm), provided the I.D. and O.D. notches are placed on opposite examination surfaces of the block. When cladding is not present, only one notch is required provided each examination surface is accessible during calibrations.

NOTE:

(1) Notches shall be located not closer than $\frac{1}{2}T$ or $\frac{1}{2}$ in. (13 mm), whichever is greater, to any block edge or to other notches.

Figure 2: Calibration Block for Piping



Procedure:

1. Place two similar angle beam search units on the calibration block or mock-up to be used in the position shown above.
2. Using through transmission methods, maximize the indication obtained and obtain a dB value of the indication.
3. Transfer the same two search units to the part to be examined, orient in the same direction in which scanning will be performed, and obtain a dB value of indications as explained above from the least three locations.
4. The difference in dB between the calibration block or mock-up and the average of that obtained from the part to be examined should be recorded and used to adjust the standard sensitivity.

Figure 3: determination of transfer correction

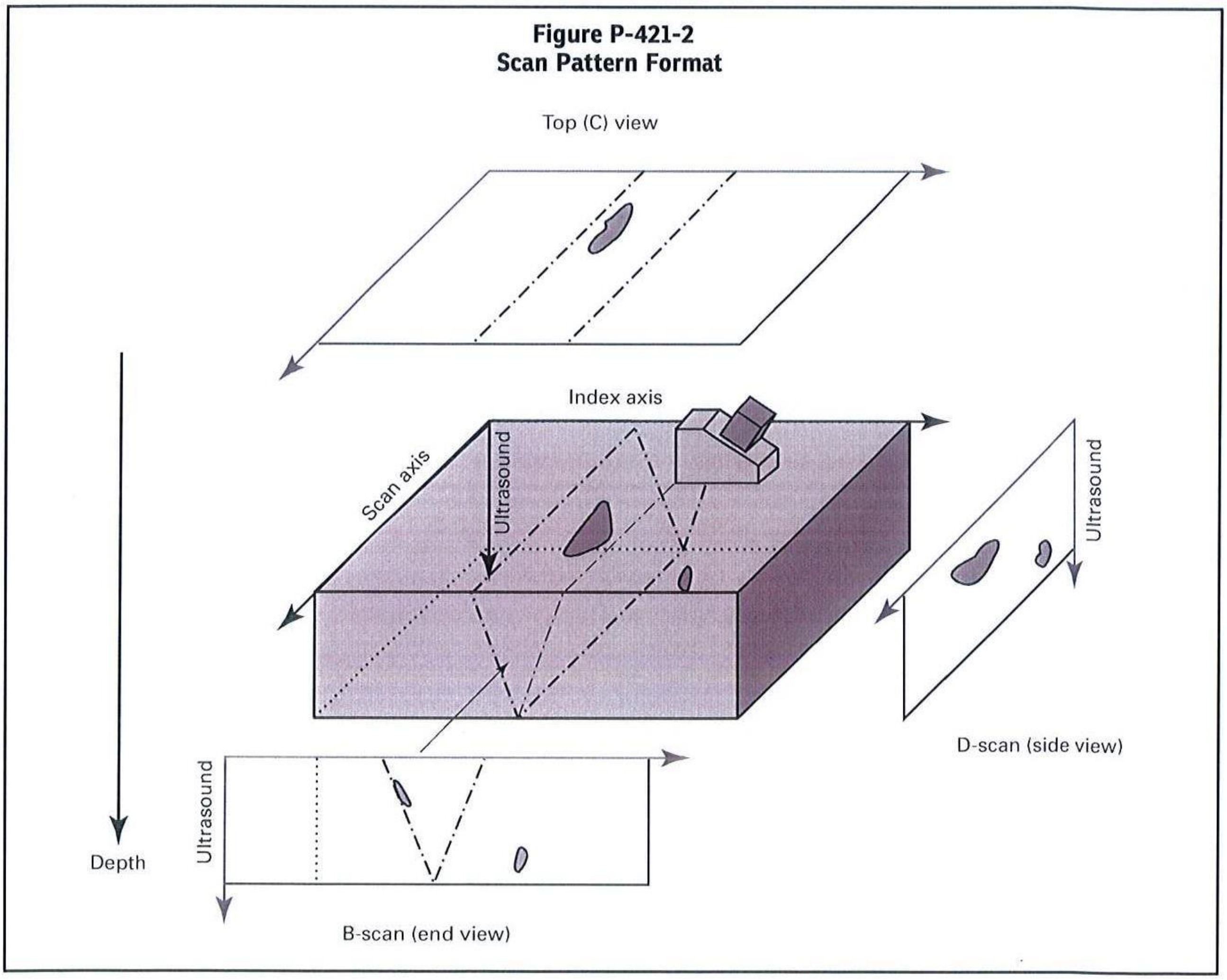


Figure 4: Volume-corrected B-scan, C-scan and D-scan displays

Appendix I [V-421]

Requirements of Phased Array Linear Scanning Examination Procedures

Table V-421
Requirements of Phased Array Linear Scanning Examination Procedures

Requirements (as Applicable)	Workmanship		Fracture Mechanics	
	Essential	Nonessential	Essential	Nonessential
Weld configurations examined, including joint design thickness and base material product form	X	...	X	...
Surfaces from which examination is performed	X	...	X	...
Surface condition (examination surface, calibration block)	X	...	X	...
Weld axis reference system and marking	X	...	X	...
Personnel qualification requirements	X	...	X	...
Personnel performance demonstration (if required)	X	...	X	...
Primary reference reflector and level	X	...	X	...
Calibration [calibration block(s) and technique(s)]	X	...	X	...
Standardization method and reflectors (wedge delay, sensitivity, TCG)	X	...	X	...
Computerized data acquisition	X	...	X	...
Wedge cut/natural refracted angle	X	...	X	...
Wedge contouring and/or stabilizing features	X	...	X	...
Wedge height	X	...	X	...
Wedge roof angle, if applicable	X	...	X	...
Wedge type (solid wedge, water column, etc.)	X	...	X	...
Wedge material	X	...	X	...
Scanner type and fixturing	X	...	X	...
Search unit mechanical fixturing device (manufacturer and model), adhering and guiding mechanism	X	...	X	...
Search unit separation, if applicable	X	...	X	...
Couplant brand name or type	...	X	...	X
Instrument manufacturer and model, including all related operating modules	X	...	X	...
Instrument software and revision [Note (1)]	X	...	X	...
Use of separate data analysis software and revision [Note (1)]	X	...	X	...
Search unit type (linear, dual linear, dual matrix, tandem, etc.)	X	...	X	...
Search unit detail (frequency, element size, number pitch, gap dimensions, element shape)	X	...	X	...
Technique(s) (straight beam, angle beam, contact, and/or immersion)	X	...	X	...
Angle(s) and mode(s) of wave propagation in the material	X	...	X	...
Direction and extent of scanning	X	...	X	...
Scanning technique (line vs. raster)	X	...	X	...
Scanning technique (automated vs. semiautomated)	X	...	X	...
Scanning (manual vs. encoded)	X	...	X	...
Scan increment (decrease in overlap)	X	...	X	...
Use of scan gain over primary reference level	X	...	X	...
Virtual aperture size (i.e., number of elements, effective height, and element width)	X	...	X	...
Focus length and plane (identify plane projection, depth, or sound path, etc.)	X	...	X	...
For E-scan				
Range of element numbers used (i.e., 1–126, 10–50, etc.)	X	...	X	...
Element incremental change (i.e., 1, 2, etc.)	X	...	X	...
Rastering angle	X	...	X	...
Aperture start and stop numbers	X	...	X	...
For S-scan:				
Aperture element numbers (first and last)	X	...	X	...
Decrease in angular range used (i.e., 40 deg to 50 deg, 50 deg to 70 deg, etc.)	X	...	X	...
Maximum angle incremental change (i.e., $\frac{1}{2}$ deg, 1 deg, etc.)	X	...	X	...
For compound E-scan and S-scan: all E-scan and S-scan variables apply	X	...	X	...
Digitizing frequency	X	...	X	...
Net digitizing frequency (considers digitization frequency together with points quantity or other data compression)	X	...	X	...
Instrument dynamic range setting	X	...	X	...
Pulser voltage	X	...	X	...
Pulse type and width	X	...	X	...
Filters and smoothing	X	...	X	...

Appendix I [V-421]

Requirements of Phased Array Linear Scanning Examination Procedures (Cont'd)

Table V-421
Requirements of Phased Array Linear Scanning Examination Procedures (Cont'd)

Requirements (as Applicable)	Workmanship Essential	Workmanship Nonessential	Fracture Mechanics Essential	Fracture Mechanics Nonessential
Pulse repetition frequency	X	...	X	...
Maximum range setting	X	...	X	...
Use of digital gain	X	...	X	...
Method for discriminating geometric from flaw indications	X	...	X	...
Flaw characterization methodology	X	...	NA	NA
Method for measuring flaw length	X	...	X	...
Method for measuring flaw height	NA	NA	X	...
Method for determining indication location relative to surface	NA	NA	X	...
Method for determining indication relative to other indications	NA	NA	X	...
Records, including minimum calibration data to be recorded (e.g., instrument settings)	...	X	...	X
Post-exam cleaning	...	X	...	X

GENERAL NOTE: NA = not applicable.

NOTE:
(1) Use of later software revisions shall be evaluated by the Level III for their impact on the functions as used. A limited extension of qualification may be determined to prove software functions. For example, addition of a software feature more capable than that already qualified may be qualified by reanalysis of existing data. If a revision is implemented, personnel shall receive training in use of the revised software.

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