UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

February 1, 1983

Regulatory Guide 1.150
Revision 1

REGULATORY GUIDE DISTRIBUTION LIST (DIVISION 1)

SUBJECT: REVISION 1 TO REGULATORY GUIDE 1.150

The original version of Regulatory Guide 1.150, "Ultrasonic Testing of Reactor Vessel Welds During Preservice and Inservice Examinations," dated June 1981, was reviewed by the Ad Hoc Committee of the Electric Utility Industry. The Committee's review resulted in their recommending an alternative method, which was presented in "Final Report - Recommended Changes to Regulatory Guide 1.150," August 1982.

The NRC staff has evaluated the recommended alternative method in the report and finds it an acceptable alternative. Therefore, this alternative method has been added to the regulatory positions in Regulatory Guide 1.150, and this Revision 1 is being issued as an active guide without prior issuance as a draft guide for comment.

Of course, comments and suggestions for improvements in guides are encouraged at all times. Guides will be revised, as appropriate, to accommodate comments and to reflect new information or experience.

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U.S. NUCLEAR REGULATORY COMMISSION

Revision 1
February 1983

REGULATORY GUIDE

OFFICE OF NUCLEAR REGULATORY RESEARCH

REGULATORY GUIDE 1.150

ULTRASONIC TESTING OF REACTOR VESSEL WELDS DURING PRESERVICE AND INSERVICE EXAMINATIONS

A. INTRODUCTION

Criterion 1, "Quality Standards and Records," of Appendix A, "General Design Criteria for Nuclear Power Plants," to 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities," requires, in part, that components important to safety be tested to quality standards commensurate with the importance of the safety functions to be performed. Where generally recognized codes and standards are used, these codes and standards must be evaluated to determine their adequacy and sufficiency and must be supplemented or modified as necessary to ensure a quality product in keeping with the required safety function. Criterion 1 further requires that a quality assurance program be implemented in order to provide adequate assurance that these components will satisfactorily perform their safety functions and that appropriate records of the testing of components important to safety be maintained by or under the control of the nuclear power unit licensee throughout the life of the unit.

Section 50.55a, "Codes and Standards," of 10 CFR Part 50 requires, in part, that structures, systems, and components be designed, fabricated, erected, constructed, tested, and inspected to quality standards commensurate with the importance of the safety function to be performed. Section 50.55a further requires that American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME B&PV Code) Class 1 components meet the requirements set forth in Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components," of the ASME Code.

Criterion XII, "Control of Measuring and Test Equipment," of Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants," to 10 CFR Part 50 requires, in part, that measures be established to ensure that instruments used in activities affecting quality are properly controlled, calibrated, and adjusted at specified periods to maintain accuracy within necessary limits.

Criterion XVII, "Quality Assurance Records," of Appendix B requires, in part, that sufficient records be maintained to furnish evidence of activities affecting quality. Consistent with applicable regulatory requirements, the applicant is required to establish such requirements concerning record retention as duration, location, and assigned responsibility.

This guide describes procedures acceptable to the NRC staff for implementing the above requirements with regard to the preservice and inservice examinations of reactor vessel welds in light-water-cooled nuclear power plants by ultrasonic testing (UT). The scope of this guide is limited to reactor vessel welds and does not apply to other structures and components such as piping.

B. DISCUSSION

Reactor vessels must periodically be volumetrically examined according to Section XI of the ASME Code, which is incorporated by reference, with NRC staff modifications, in §50.55a of 10 CFR Part 50. The rules of Section XI require a program of examinations, testing, and inspections to evidence adequate safety. To ensure the continued structural integrity of reactor vessels, it is essential that flaws be reliably detected and evaluated. It is desirable that results from prior UT examinations be compared to results from subsequent examinations so that flaw growth rates may be estimated. Lack of reliability of UT examination results is partly due to the reporting of ambiguous results, such as reporting the length of flaws to be shorter during subsequent examinations. This lack of reproducibility arises because the Code requirements are not specific about many essential variables in the UT procedures. Recommendations of this guide provide guidance that would help to obtain reproducibility of results. Reporting of UT indications as recommended in this guide will help to provide a means for assessing the ambiguity of the reported data.

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This guide was issued after consideration of comments received from the public. Comments and suggestions for improvements in these guides are encouraged at all times, and guides will be revised, as appropriate, to accommodate comments and to reflect new information or experience.

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Operating and licensing experience[1,2,3] and industry tests[4] have indicated that UT procedures that have been used for examination of reactor vessel welds may not be adequate to consistently detect and reliably characterize flaws during inservice examination of reactors. This lack of reproducibility of location and characterization of flaws has resulted in the need for additional examinations and evaluations with associated delays in the licensing process.

1. INSTRUMENT SYSTEM PERFORMANCE CHECKS

Instrument system performance checks to determine the characteristics of the UT system should be performed at intervals short enough to permit each UT examination to be correlated with particular system performance parameters to help compare results. These determinations will help make it possible to judge whether differences in observations made at different times are due to changes in the instrument system characteristics or are due to real changes in the flaw size and characteristics. Determinations for "Frequency-Amplitude Curve" and "Pulse Shape" recommended in regulatory positions 1.4 and 1.5 may be made by the licensee's examination agent by using any of the common industry methods for measuring these parameters as long as these methods are adequately documented in the examination record. These measurements may be performed in the laboratory before and after each examination, provided the identical equipment combination (i.e., instrumentation, cable, and search unit) is used during the examination.

These determinations are to aid third-party evaluations when different equipment is used to record indications on subsequent examinations and are not intended to qualify systems for use.

The intent of regulatory position 1.5 is to establish the instrument pulse shape in a way that actual values of pulse length and voltages can be observed on an oscilloscope. The calibrated time base does not necessarily have to follow the time base of the distance-amplitude correction (DAC) curve but may be chosen to suitably characterize the initial pulse. The pulse shape record will assist in analyzing potential differences in flaw response between successive examinations (i.e., is the difference due to flaw growth or system change).

Pulse shape is best determined by using a high-impedance oscilloscope with the transducer disconnected from the instrument.

2. CALIBRATION

According to Appendix I, Article I, I-4230, Section XI of the ASME Code, 1974 edition, instrument calibration for performance characteristics (amplitude linearity and amplitude control linearity) is to be verified at the beginning of each day of examination. Requirements in Article 4, Section V, 1977 edition, which is referenced by Section XI, for the periodic check of instrument characteristics (screen height linearity, amplitude control linearity, and beam spread measurements) for UT examination of reactor pressure vessels have been relaxed. The interval between periodic checks has been extended from a period of 1 day to a period of extended use or every 3 months, whichever is less. This change has not been justified on the basis of statistically significant field data. Performance stability of automated electronic equipment is dependent on system performance parameters (essential variables), and the ASME Code has no quality standards to control these performance parameters. Until the performance stability of UT systems can be ensured by the introduction of quality standards, it is not reasonable to increase the period between calibration checks. Therefore, recommendations have been made to check instrument performance parameters more frequently than is specified in the ASME Code.

Requirements of Appendix I, Article I, I-4230, Section XI of the ASME Code, 1974 edition, state:

> "System calibration shall be checked by verifying the distance-amplitude correction curve (I-4420 or I-4520) and the sweep range calibration (I-4410 or I-4510) at the start and finish of each examination, with any change in examination personnel, and at least every 4 hours during an examination."

In the 1977 edition, these requirements were changed. According to Article 4 (T-432.1.2), Section V of the ASME Code, 1977 edition, the following applies:

> "A calibration check on at least one of the basic reflectors in the basic calibration block or a check using a simulator shall be made at the finish of each examination, every 4 hours during the examination and when examination personnel are changed."

This requirement has several minor deficiencies, including the following:

a. One-Point Check

A calibration check is now required on only one of the basic reflectors. As a result, the accuracy of only one point on the DAC curve, and not the accuracy of three points as previously required, is checked. This alteration would permit the instrument drift for other metal path distances to go unnoticed, which is not desirable.

b. Secondary Reference

The change allows a one-point check by a mechanical or electronic simulator instead of a check against the basic calibration block. A mechanical simulator could be a plastic, steel, or aluminum block with a single reference reflector, which may be a hole or a notch. Without specified details, the electronic simulator could be any device that

[1] "Ultrasonic Reinspection of Pilgrim 1 Reactor Vessel Nozzle N2B," John H. Gieske, NUREG-6502.

[2] "Summary Hatch Nuclear Plant Unit 1 Reactor Pressure Vessel Repair," 1972, Georgia Power Company.

[3] "Summary of the Detection and Evaluation of Ultrasonic Indications - Edwin Hatch Unit 1 Reactor Pressure Vessel," January 1972, Georgia Power Company.

[4] Round robin tests conducted by the Pressure Vessel Research Committee (PVRC) of the Welding Research Council for UT of thick section steels.

provides an electrical signal. With the resulting uncertainty, there may be errors in checking against the secondary reference (simulator), the magnitude of which is undefined and unknown.

c. Electronic Simulator

Subarticle T-432.1.3 of Article 4, Section V of the ASME Code, 1977 edition, allows the use of an electronic simulator and also permits the transducer sensitivity to be checked separately. Both these provisions may introduce errors that will be very difficult to detect.

To avoid the introduction of errors and to ensure repeatability of examinations at a later date, it would be advisable to check the calibration of the entire system rather than that of individual components. Checking system calibration without the transducer and the cable is not advisable because these tests do not detect possible leakage or resistance changes at the connectors. This is especially important when the UT examination is performed under conditions of high humidity or under water and the connectors may not be waterproof or moistureproof. Checking the transducer sensitivity separately (sometimes weeks in advance) also neglects the effects of possible damage due to transport or use. The transducer characteristics may change because of damage to or degradation of internal bonding agents or inadvertent damage to the transducer element. Further, the use of an electronic block simulator (EBS) as a secondary standard introduces an error band in the calibration process. The error band may depend on, among others, the following factors:

(1) Drift due to ambient temperature change.
(2) Drift due to high temperature storage.
(3) Drift due to high humidity storage.
(4) Drift due to vibration and shock loading during shipment.
(5) Degradation of the memory device used to store the reference signal information due to vibration, shock, aging, or heat effects.

To ensure stability, computer systems are generally kept in an air conditioned environment; however, EBS systems are not usually kept in a controlled environment.

Error band for one particular type of instrument[5] was determined to be in the range of ±6 percent. The error band for other instruments may be in a different range and may vary for the same instrument if memory devices or components of different quality are used at a later date. The error band is dependent on the temperature extremes, shock loadings, and vibrations suffered by the instrument. Since the error band value depends on these parameters, it would be advisable to ensure, through recording instruments, that the EBS was not subjected to higher temperatures (container lying in the sun) and greater shock (container dropped) during transport than those parameters that served as a basis for defining the error band.

Use of electronic simulators would be permissible if they can check the calibration of the UT system as a whole and the error band introduced by their use can be relied on and taken into consideration.

d. Static Versus Dynamic Reflector Responses

With some automated systems, the DAC curve is manually established. In these cases, the signal is maximized by optimizing the transducer orientation toward the calibration holes. Subsequently, detection and sizing of flaws are based on signals received from a moving transducer where no attempt is made (or it is not possible) to maximize the signal even for significant flaws. This procedure neglects several sources of error introduced by the possible variation in signal strength caused by:

(1) Differences between the maximized signal and the unmaximized signal.

(2) Loss in signal strength due to the separation of the transducer from the metal surface because of the viscosity of the coupling medium (planing effects).

(3) Variation in contact force and transducer coupling efficiency.

(4) Loss in signal strength due to structural vibration effects in the moving transducer mount and other driving mechanisms.

(5) Loss in signal strength due to the tilting caused by the mounting arrangement in some transducer mounts.

Because of the above, it would be advisable to establish the DAC curve under the same conditions as those under which scanning is performed to obtain data for detection and sizing. It would be acceptable to establish a DAC curve by maximizing signal strength during manual scans when signals are also maximized for flaw sizing. However, it would not be advisable to use manually maximized signals to establish the DAC curve when data are obtained later by mechanized transducers (where signals cannot be maximized) for the detection and sizing of flaws without adjustment for the potential error introduced. In these situations, an acceptable method would be to establish DAC curves using moving transducers or to establish correction factors that may be used to adjust signal strength. It would be prudent to use care and planning in establishing correction factors. For example, establishing a ratio between a dynamic and static mode under laboratory conditions using a precision transducer drive and stiff mounting may have very little in common with the transducer mounting and traverse conditions of the actual examination setup. If correction factors are to be used, it would be worthwhile to build either full-scale mockups or consider the variation of all the important parameters in a suitable model taking into

[5] "Calibration Verification of Ultrasonic Examination Systems with the Electronic Block Simulator," D. J. Boomgard et al., August 1979, Report No. WCAP-9545, Westinghouse Electric Corporation, Nuclear Service Division, P.O. Box 2728, Pittsburgh, PA 15230.

consideration scaling laws on variables such as mass, vibration, and stiffness constants. It would be advisable to confirm the scaling law assumptions and predictions for vibration and viscosity effects before correction factors are used for setting scanning sensitivity levels.

Differences in the curvature and surface finish between calibration blocks and vessel areas could change the dynamic response, so it may be advisable to establish correction factors between dynamic and static responses from the indications that are found during examination. This would avoid the difficulties associated with establishing a dynamic response DAC curve and still take all the factors into consideration.

e. Secondary DAC

During some manual scans, the end point of the DAC curve may fall below 20 percent of the full screen height. When this happens, it is difficult to evaluate flaws on the 20 percent and 50 percent DAC basis in this region since the 20 percent and 50 percent DAC points may be too close to the baseline. To overcome this difficulty, it is advisable that a secondary DAC curve using a higher-gain setting be developed so that 20 percent and 50 percent DAC points may be easily evaluated. For this purpose, it is advisable that the gain be increased sufficiently to keep the lowest point of the secondary DAC curve above 20 percent of screen height.

The secondary DAC curves need not be generated unless they are required. If electronic DAC is used and amplitudes are maintained above 20 percent of full screen height, a secondary DAC would not be necessary.

f. Component Substitution

A calibration check should be made each time a component is put back into the system to ensure that such components as transducers, pulsers, and receivers were not damaged while they were in storage. This will ensure elimination of the error band and mistakes in resetting the various control knobs.

g. Calibration Holes

Comparison of results between examinations performed at different times may be facilitated if the same equipment is used and if the reflections from growing flaws can be compared to the same reference signal. Reference signals obtained from a calibration block depend on, among other things, the surface roughness of the block and the reflector holes. Therefore, these surfaces should be protected from corrosion and mechanical damage and also should not be altered by mechanical or chemical means between successive examinations. If the reference reflector holes or the block surface are given a high polish by any chemical or mechanical means, the amplitude of the reflections obtained from these reflector holes may be altered. Polishing the holes or the block surface is not forbidden by the ASME Code. However, this possibly altered amplitude could affect the sizing of indications found during any examination. At this time, no recommendations are being made to control the surface roughness of the block or the above-mentioned reflector holes; however, if the block or these holes are polished, this fact should be recorded for consideration if a review of the UT data becomes necessary at a later date.

3. NEAR-SURFACE EXAMINATION AND SURFACE RESOLUTION

Sound beam attenuation in any material follows a decaying curve (exponential function); however, in some cases the reflection from the nearest hole is smaller than the reflection from a farther hole. This makes it difficult to draw a proper DAC curve. In such cases, it may be desirable to use a lower frequency or a smaller transducer for flaw detection near the beam-entry surface to overcome the difficulty of marginal detectability.

Near-field effects, decay time of pulse reflections, shadow effects, restricted access, and other factors do not permit effective examination of certain volume areas in the component. To present a clear documentation and record of the volume of material that has not been effectively examined, these volume areas need to be identified. Recommendations are provided to best estimate the volume in the region of interest that has not been effectively examined, such as volumes of material near each surface (because of near-field effects of the transducer and ring-down effects of the pulse due to the contact surface), volumes near interfaces between cladding and parent metal, and volumes shadowed by laminar flaws.

4. BEAM PROFILE

Beam profile is one of the main characteristics of a transducer. It helps to show the three-dimensional distribution of beam strength for comparing results between examinations and also for characterizing flaws. The beam profile needs to be determined and recorded so that comparisons may be made with results of successive examinations.

5. SCANNING WELD-METAL INTERFACE

The amount of energy reflected back from a flaw is dependent on its surface characteristics, orientation, and size. The present ASME Code procedures rely on the amplitude of the reflected signal as a basis for judging flaws. This means that the size estimation of a defect depends on the proportion of the ultrasonic beam reflected back to the probe. The reflection behavior of a planar defect, which largely depends on the incident beam angle when a single search unit is used to characterize the flaw, is thus a decisive factor in flaw estimation. The larger the size of a planar defect, the narrower is the reflected sound beam. The narrow reflected sound beam makes the flaw very difficult to detect in most cases (unless the beam angle is right).[6,7]

[6] "Probability of Detecting Planar Defects in Heavy Wall Welds by Ultrasonic Techniques According to Existing Codes," Dr. Ing. Hans-Jurgen Meyer, Quality Department of M.A.N., Nurnberg, D 8500 Nurnberg 115.

[7] "Reflection of Ultrasonic Pulses from Surfaces," Haines and Langston Central Electricity Generating Board, U.K. (CESB) Report Number RD 18/N4115.

Therefore, the beam angles used to scan welds should be optimized and should be based on the geometry of the weld/parent-metal interface. At least one of these angles should be such that the beam is almost perpendicular (±15 degrees to the perpendicular) to the weld/parent-metal interface, unless it can be demonstrated that large (Code-unacceptable) planar flaws unfavorably oriented, parallel to the weld-metal interface, can be detected by the UT technique being used. In vessel construction, some weld preps are essentially at right angles to the metal surface. In these cases, use of shear wave angles close to 75 degrees is not recommended. Two factors would make the use of shear wave angles close to 75 degrees inadvisable, – first, the test distances necessary become too large resulting in loss of signal, and second, the generation of surface waves tends to confuse the interpretation of results. In these cases, use of alternative volumetric nondestructive examination (NDE) techniques, as permitted by Subarticle IWA-2240, Section XI of the ASME Code, should be considered. Alternative NDE techniques to be considered may include high-intensity radiograph or tandem-probe ultrasonic examination of the weld-metal interface. To avoid the possibility of missing large flaws, particularly those that have an unfavorable orientation, it is desirable that the back reflection amplitude, while scanning with a straight beam, be monitored over the entire volume of the weld and adjacent base metal. Any area where a reduction of the normal back-surface reflection amplitude exceeds 50 percent should be examined by angle beams in increments of ±15 degrees until the reduction of signal is explained. Where this additional angle beam examination is not practical, it may be advisable to consider examining the weld by a supplementary volumetric NDE technique.

6. SIZING

The depth or through-wall dimension of flaws is more significant than the length dimension, according to fracture mechanics analysis criteria. Using the single-probe pulse-echo technique, it is possible, depending on flaw orientation, that some large flaws may not reflect much energy to the search unit.[6] Because of this possibility, the depth dimension of the flaw should be conservatively sized unless there is evidence to prove that the flaw orientation is at right angles to the beam. It is recommended that indications that are associated with through-thickness flaws and do not meet Code-allowable criteria or criteria recommended in this guide be sized at 20 percent DAC as well as at 50 percent DAC.

In certain cases, it is possible for various reasons that a flaw would not reflect enough energy to the search unit to make the indication height 50 percent of the DAC curve height. However, if such a flaw were large, a persistent signal could be obtained over a large area. It is therefore recommended that all continuous signals that are 20 percent of DAC with transducer travel movement of more than 1 inch plus the beam spread (as defined in Article 4, nonmandatory Appendix B, Section V of the ASME Code, 1977 edition) should be considered significant and should be recorded and investigated further. The beam spread effect in some cases can make very small flaws appear to be large when judged at 20 percent DAC; hence, beam spread has to be considered in judging the significance of flaws.[8] It is therefore recommended that only signals with a total transducer travel movement greater than the beam spread should be considered significant.

7. REPORTING OF RESULTS

This guide gives recommendations for recording the characteristics of the UT examination system. This information can be of significance in later analysis for determining the location, dimensions, orientation, and growth rate of flaws.

Records pertaining to UT examinations should be considered quality assurance records. Recommendations on the collection, storage, and maintenance of these records are given in Regulatory Guide 1.88, "Collection, Storage, and Maintenance of Nuclear Power Plant Quality Assurance Records." Availability of these records at a later date will permit a review of the UT results from the data gathered during previous ultrasonic examinations.

When ultrasonic examination is performed, certain volumes of material such as the following are not effectively examined:

a. Material volume near the front surface because of near-field effects, cladding disturbance, or electronic gating.

b. Material volume near the surface because of surface roughness or unfavorable flaw orientations.

c. Volumes shadowed by insulation or part geometry.

In some cases, as much as 1 inch (25.4 mm) or more below the surface is not examined because of the electronic gate setting. This means that the unexamined volume may contain flaws that would be unacceptable according to Section XI, ASME Code, as follows:

a. Without evaluation (deeper than approximately 0.2 inch).

b. Even after evaluation (deeper than approximately 0.85 inch).

Assuming an aspect ratio of 0.1, according to IWB-3510.1, Section XI, ASME Code, flaws 0.2 inch deep would be unacceptable for a 9-inch wall thickness.

Typically a BWR reactor pressure vessel (RPV) wall in the beltline region is 6 inches thick and a PWR-RPV wall is 8.5 inches thick. During flaw evaluation, where the wall temperature is high and the available toughness is high, and the calculated critical surface flaw depth (a_c) exceeds the wall thickness (t), a_c is taken[9] as the wall thickness. According to IWB-3600, Section XI, the allowable end-of-life size is $a_f = 0.1a_c$. Flaws exceeding this allowable value, which would

[8] "Ultrasonic Examination Comparison of Indication and Actual Flaw in RPV," Ishi Kawajima-Harima Industries Co., Ltd., January 1976.

[9] "Flaw Evaluation Procedures: ASME Section XI-EPRI," NP-719-SR, special report, August 1978.

be 0.85 inch for a PWR and 0.65 inch for a BWR, will have to be repaired. The above example illustrates the importance of blanking out the electronic indication signals and not examining the surface volume to a depth of 1 inch. Since the flaws that can be missed because of electronic gating may be larger than the flaws permitted with or without evaluation, this unexamined volume is important and needs to be identified.

In certain specific cases, areas were not examined because insulation was in the way and the transducer could not scan the volume of interest. NRC was not informed of this situation until much later. In view of the above and to avoid licensing delays, it is advisable that the volume of areas not examined for any or all of the above reasons be reported.

The volumes of material that are not effectively examined depend on the particular part geometry and unique situations associated with each RPV. During identification of the material volumes that have not been examined, consideration should be given to the types of flaws that are currently being reported in some of the operating plants. These include stress corrosion cracks in the heat-affected zone, fatigue cracks, and cracks that are close to the surface and sometimes penetrate the surface. These volumes of material should be identified and reported to NRC along with the report of welding and material defects in accordance with the recommendation of regulatory position 2.a(3) of Regulatory Guide 1.16, "Reporting of Operating Information–Appendix A Technical Specifications."

C. REGULATORY POSITION

Ultrasonic examination of reactor vessel welds should be performed according to the requirements of Section XI of the ASME B&PV Code, as referenced in the Safety Analysis Report (SAR) and its amendments, supplemented by the following:

1. INSTRUMENT PERFORMANCE CHECKS

The checks described in paragraphs 1.2 through 1.5 should be made for any UT system used for the recording and sizing of reflectors in accordance with regulatory position 6 and for reflectors that exceed the Code-allowable criteria.

1.1 Frequency of Checks

As a minimum, these checks should be verified within 1 day before and within 1 day after examining all the welds that need to be examined in a reactor pressure vessel during one outage. Pulse shape and noise suppression controls should remain at the same setting during examination and calibration.

1.2 Screen Height Linearity

Screen height linearity of the ultrasonic instrument should be determined according to the mandatory Appendix I to Article 4, Section V of the ASME Code, within the time limits specified in regulatory position 1.1.

1.3 Amplitude Control Linearity

Amplitude control linearity should be determined according to the mandatory Appendix II of Article 4, Section V of the ASME Code, 1977 edition, within the time limits specified in regulatory position 1.1.

1.4 Frequency-Amplitude Curve

A photographic record of the frequency-amplitude curve should be obtained. This record should be available for comparison at the inspection site for the next two successive inspections of the same volume. The reflector used in generating the frequency-amplitude curves as well as the electronic system (i.e., the basic ultrasonic instrument, gating, form of gated signal, and spectrum analysis equipment) and how it is used to capture the frequency-amplitude information should be documented.

1.5 Pulse Shape

A photographic record of the unloaded initial pulse against a calibrated time base should be obtained. The time base and voltage values should be identified and recorded on the horizontal and vertical axis of the above photographic record of the initial pulse. The method used in obtaining the pulse shape photograph, including the test point at which it is obtained, should be documented.

2. CALIBRATION

System calibration should be checked to verify the DAC curve and the sweep range calibration per nonmandatory Appendix B, Article 4, Section V of the ASME Code, as a minimum, before and after each RPV examination (or each week in which it is in use, whichever is less) or each time any component (e.g., transducer, cable, connector, pulser, or receiver) in the examination system is changed. Where possible, the same calibration block should be used for successive in-service examinations of the same RPV. The calibration side holes in the basic calibration block and the block surface should be protected so that their characteristics do not change during storage. These side holes or the block surface should not be modified in any way (e.g., by polishing) between successive examinations. If the block surface or the calibration reflector holes have been polished by any chemical or mechanical means, this fact should be recorded.

2.1 Calibration for Manual Scanning

For manual scanning for the sizing of flaws, static calibration may be used if sizing is performed using a static transducer. When signals are maximized during calibration, they should also be maximized during sizing. For manual scanning for the detection of flaws, reference hole detection should be shown at scanning speed and detection level set accordingly (from the dynamic DAC).

2.2 Calibration for Mechanized Scanning

When flaw detection and sizing are to be done by mechanized equipment, the calibration should be performed using the following guidelines:

a. Calibration speed should be at or higher than the scanning speed.

b. The direction of transducer movement during calibration should be the same as the direction during scanning unless (1) it can be shown that the change in scanning direction does not make a difference in the sensitivity and vibration background noise received from the search unit or (2) these differences are taken into account by a correction factor.

c. For mechanized scanning, signals should not be maximized during the establishment of the DAC curve.

d. One of the following alternative guidelines should be followed for establishing the DAC curve:

(1) The DAC curve should be established using a moving transducer mounted on the mechanism that will be used for examination of the component.

(2) Correction factors between dynamic and static response should be established using full-scale mockups.

(3) Correction factors should be established using models and taking scaling factors into consideration (assumed scaling relationship should be verified).

(4) Correction factors between dynamic and static response should be established from the indications that are found during examination for sizing. For detection of flaws during the initial scan, correction factors may be assumed based on engineering judgment. If assumed correction factors are used for detection, these factors should later be confirmed on indications from flaws in the vessel during the examination. Deviation from the assumed value may suggest reexamining the data.

2.3 Calibration Checks

If an EBS is used for calibration check, the following should apply:

a. The significant DAC percentage level used for the detection and sizing of indications should be reduced to take into account the maximum error that could be introduced in the system by the variation of resistance or leakage in the connectors or other causes.

b. Calibration checks should be performed on the complete connected system (e.g., transducer and cables should not be checked separately).

c. Measures should be taken to ensure that the different variables such as temperature, vibration, and shock limits for which the EBS error band is determined are not exceeded during transport, use, storage, etc.

d. When a universal calibration block is used and some or all of the reference holes are larger than the reflector holes at comparable depths recommended by Article 4, Section V, of the ASME Code, 1980 edition, a correction factor should be used to adjust the DAC level to compensate for the larger reflector holes. Also, if the reactor pressure vessel has been previously examined by using a conventional block, a ratio between the DAC curves obtained from the two blocks should be noted (for reference) with the significant indications data.

3. NEAR-SURFACE EXAMINATION AND SURFACE RESOLUTION

The capability to effectively detect defects near the front and back surfaces of the actual component should be estimated. The results should be reported with the report of abnormal degradation of reactor pressure boundary in accordance with the recommendation of regulatory position 2.a(3) of Regulatory Guide 1.16. In determining this capability, the effect of the following factors should also be considered:

a. If an electronic gate is used, the time of start and stop of the control points of the electronic gate should be related to the volume of material near each surface that is not being examined.

b. The decay time, in terms of metal path distance, of the initial pulse and of the pulse reflections at the front and back surface should be considered.

c. The disturbance created by the clad-weld-metal interface with the parent metal at the front or the back surface should be related to the volume of material near the interface that is not being examined.

d. The disturbance created by front and back metal surface roughness should be related to the volume of material near each surface that is not being examined.

4. BEAM PROFILE

The beam profile should be determined if any recordable flaws are detected. This should be done for each search unit used during the examination by a procedure similar to that outlined in the nonmandatory Appendix B (B-60), Article 4, Section V of the ASME Code, 1980 edition, for determining beam spread. Beam profile curves should be determined for each of the holes in the basic calibration block. Interpolation may be used to obtain beam profile correction for assessing flaws at intermediate depths for which the beam profile has not been determined.

5. SCANNING WELD-METAL INTERFACE

The beam angles used to scan welds should be based on the geometry of the weld/parent-metal interface. At least one of these angles should be such that the beam is almost perpendicular (±15 degrees to the perpendicular) to the weld/parent-metal interface unless it can be demonstrated that unfavorably oriented planar flaws can be detected by

the UT technique being used. Otherwise, use of alternative volumetric NDE techniques, as permitted by the ASME Code, should be considered. Alternative NDE techniques may be considered to include high-intensity radiography or tandem-probe ultrasonic examination of the weld-metal interface.

6. SIZING

Indications from geometric sources need not be recorded.

6.1 Traveling Indications

Indications that travel on the horizontal baseline of the scope for a distance greater than indications from the calibration holes (at 20 percent DAC amplitude) should be recorded. Indications that travel should be recorded and sized at 20 percent DAC. Where the indication is sized at 20 percent DAC, this size may be corrected by subtracting for the beam width in the through-thickness direction obtained from the calibration hole (between 20 percent DAC points) that is at a depth similar to the flaw depth. If the indication exceeds 50 percent DAC, the size should be recorded by measuring the distance between 50 percent DAC levels without using the beam-width correction. The determined size should be the larger of the two.

6.2 Nontraveling Indications

Nontraveling indications above 20 percent DAC level that persist for a scanning distance of more than 1 inch plus the beam spread between 20 percent DAC points (as defined by nonmandatory Appendix B, Article 4, Section V of the ASME Code, 1977 edition) should be considered significant. The size of these flaws should be determined by measuring the distance between points at 50 percent DAC and between points at 20 percent DAC where the beam-width correction is made only for the 20 percent DAC size. The recorded size of the flaw would be the larger of the two determinations. If it can be adequately demonstrated that a nontraveling indication is from a geometric source (and not a flaw), there is no need to record that indication.

The following information should also be recorded for indications that are reportable according to this regulatory position:

a. Indications should be recorded at scan intervals no greater than one-fourth inch.

b. The recorded information should include the indication travel (metal path length) and the transducer position for 10 percent, 20 percent, 50 percent, and 100 percent DAC and the maximum amplitude of the signal.

7. REPORTING OF RESULTS

Records[10] obtained while following the recommendations of regulatory positions 1.2, 3, 5, and 6, along with discussions and explanations, if any, should be kept available at the site for examination by the NRC staff. If the size of an indication, as determined in regulatory positions 6.1 or 6.2, equals or exceeds the allowable limits of Section XI of the ASME Code, the indications should be reported as abnormal degradation of reactor pressure boundary in accordance with the recommendation of regulatory position 2.a(3) of Regulatory Guide 1.16.

Along with the report of ultrasonic examination test results, the following information should also be included:

a. The best estimate of the error band in sizing the flaws and the basis for this estimate should be given.

b. The best estimate of the portion of the volume required to be examined by the ASME Code that has not been effectively examined such as volumes of material near each surface because of near-field or other effects, volumes near interfaces between cladding and parent metal, volumes shadowed by laminar material defects, volumes shadowed by part geometry, volumes inaccessible to the transducer, volumes affected by electronic gating, and volumes near the surface opposite the transducer.[11]

c. The material volume that has not been effectively examined by the use of the above procedures may be examined by alternative effective volumetric NDE techniques. If one of these alternative NDE techniques is a variation of UT, recommendations of regulatory positions 1 and 3 should apply. A description of the techniques used should be included in the report. If other volumetric techniques or variations of UT are used as indicated in regulatory position 5, the effectiveness of these techniques should be demonstrated and the procedures reported for review by the NRC staff.

8. ALTERNATIVE METHOD

Appendix A contains an alternative method that is presented in Chapter 3 of the document "Recommended Changes to Regulatory Guide 1.150," prepared by the Ad Hoc Committee of the Electric Utility Industry and presented to the NRC in August 1982.[12] The NRC staff has evaluated this method and has found it to be an acceptable alternative to that presented in paragraphs 1 through 7 of this regulatory position.

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[10] Any guidance in this document related to information collection activities has been cleared under OMB Clearance No. 3150-0011.

[11] It should be noted that the licensee is required to apply for relief from impractical ASME Code requirements according to § 50.55a of 10 CFR. If the licensee is committed to examine a weld as per the inspection plan in the plant SAR, the licensee is required to file an amendment when the commitments made in the SAR cannot be met.

[12] This document is available through Mr. Larry Becker, c/o J. A. Jones Applied Research Co., P.O. Box 217097, Charlotte, North Carolina 28221.

D. IMPLEMENTATION

Except in those cases in which an applicant proposes an acceptable alternative method for complying with specified portions of the Commission's regulations, the method described herein will be used in the evaluation of (1) the results of inservice examination programs of all operating reactors after July 15, 1981, and (2) the results of preservice examination programs of all reactors under construction performed after January 15, 1982.

The recommendations of this guide are not intended to apply to preservice examinations that have already been completed. The NRC staff intends to recommend that all licensees modify their technical specifications to make them consistent with the recommendations contained herein.

APPENDIX A

ALTERNATIVE METHOD

The following is reprinted with permission from Chapter 3 of the document "Recommended Changes to Regulatory Guide 1.150," prepared by the Ad Hoc Committee of the Electric Utility Industry.

Ultrasonic examination of reactor vessel welds should be performed according to the requirements of Section XI of the ASME B&PV Code, as referenced in the Safety Analysis Report (SAR) and its amendments, supplemented by the following:

1. INSPECTION SYSTEM PERFORMANCE CHECKS

The conduct of a quality examination requires that the performance characteristics of the inspection system used be well defined and documented. This is particularly true for situations which require comparisons of examination results generated during successive examinations on the same components.

A system comprises:
a. a transducer;
b. a single channel instrument or each channel of a multi-channel instrument; and
c. a given cable type and length.

The checks described in paragraphs 1.1 and 1.2 should be made for any UT system used for inspection of reactor pressure vessel (RPV) welds.

The field performance checks described in 1.2 (with the possible exception of 1.2.c.) should be conducted on a basic calibration block that represents the thickness range to be examined.

1.1 Pre-exam Performance Checks

a. Frequency of checks

These checks should be verified within six months before reactor pressure vessel examinations performed during one outage. Pulse shape and noise suppression controls should remain at the same settings during calibration and examination.

b. RF Waveform

A record of the RF (radiofrequency) pulse waveform from a reference reflector should be obtained for each search unit used in the examination in a manner which will provide frequency amplitude information. At the highest amplitude portion of the beam, the RF return signal should be recorded before it has been rectified or conditioned for display. The reflector used in generating the RF return signal as well as the electronic system (i.e., the basic ultrasonic instrument, gating, and form of gated signal) should be documented. These records should be used for comparison with previous and future records.

1.2 Field Performance Checks

a. Frequency of Checks

As a minimum, these checks should be verified on-site before and after examining all the welds that need to be examined in a reactor pressure vessel during one outage. Pulse shape and noise suppression controls should remain at the same setting during examination and calibration.

b. Instrument Sensitivity during Linearity Checks

The initial instrument sensitivity during the performance of 1.2.e. should be such that it falls at the calibration sensitivity or at some point between the calibration sensitivity and the scanning sensitivity.

c. RF Waveform

A record of the RF (radiofrequency) pulse waveform from a reference reflector should be obtained and recorded in a manner that will permit extraction of frequency amplitude information. At the highest amplitude portion of the beam, the RF return signal should be recorded before it has been rectified or conditioned for display. This should be determined on the same reflector as that used in 1.1.b. above. This record should be retained for future reference.

d. Screen Height Linearity

Screen height linearity of the ultrasonic instrument should be determined according to the mandatory Appendix I to Article 4, Section V of the ASME Code or Appendix I to Section XI of the ASME Code.

e. Amplitude Control Linearity

Amplitude control should be determined according to the mandatory Appendix II of Article 4, Section V of the ASME Code or Appendix I to Section XI of the ASME Code.

f. Angle Beam Profile Characterization

The vertical beam profile should be determined for each search unit used during the examination by a procedure similar to that outlined in nonmandatory Appendix B-60, Article 4, Section V of the ASME Code or Appendix I to Section XI of the ASME Code. Beam profile curves should be determined at different depths to cover the thicknesses of materials to be examined. Interpolation may be used to obtain beam profile correction for assessing flaws at intermediate depths for which beam profile has not been determined.

Beam profile measurements should be made at the sensitivity required for sizing. For example, sizing to a 20 percent DAC criteria requires that the beam profile be determined at 20 percent DAC.

2. CALIBRATION

System calibration should be performed to establish the DAC curve and the sweep range calibration in accordance with Article 4, Section V of the ASME Code or Appendix I to Section XI. Calibration should be confirmed before and after each RPV examination, or each week in which the system is in use, whichever is less. Where possible, the same calibration block should be used for successive inservice examinations of the RPV.

2.1 Calibration for Manual Scanning

For manual sizing of flaws, static calibration may be used if sizing is performed using a static transducer. When signals are maximized during calibration, they should also be maximized during sizing. For manual scanning for the detection of flaws, reference hole detection should be shown at scanning speed and detection level set accordingly.

2.2 Calibration for Mechanized Scanning

When flaw detection is to be done by mechanized equipment, the calibration should be performed using the following guidelines.

a. The DAC curve should be established using either a moving transducer mounted on the mechanism that will be used for examination of the component or a mechanism that duplicates the critical factors (e.g., transducer mounting, weight, pivot points, couplant) present in the scanning mechanism.

b. Calibration speed should be at or higher than the scanning speed, except when correction factors established in 2.2.d. are used.

c. The direction of transducer movement (forward or backward) during calibration to establish the DAC curve should be the same direction during scanning unless it can be shown that a change in scanning direction does not reduce flaw detection capability.

d. One of the following alternative guidelines should be followed to establish correction factors if static calibration is used.

(1) Correction factors between dynamic and static response should be established using the basic calibration block or,

(2) Correction factors should be established using models and taking scaling factors into consideration (assumed scaling relationship should be verified) or,

(3) Correction factors should be established using full scale mockups.

2.3 Calibration Confirmation

Calibration confirmation performed as mid-shift or interim confirmation between on-site calibrations should comply with stability requirements in T-433, Article 4, Section V of the ASME Code.

When an electronic simulator is used for on-site calibration confirmation after a Code-required block calibration performed off-site, the following should also apply:

a. Complete system performance should be maintained stable prior to off-site calibrations and on-site calibration confirmation by use of target reflectors. The target reflectors should be mounted with identical physical displacement in both the off-site calibration facilities and the on-site mechanized equipment. Each on-site periodic calibration should be preceded by complete system performance verification using a minimum of two (2) target reflectors separated by a distance representing 75 percent of maximum thickness to be examined.

b. Written records of calibrations should be established for both target reflector responses and Code calibration block DAC curves for each transducer. These written records may be used to monitor drift since the original recorded calibration.

c. Measures should be taken to ensure that the different variables such as temperature, vibration, and shock limits are minimized by controlling packaging, handling, and storage.

2.4 Calibration Blocks

Calibration blocks should comply with Appendix I to Section XI or Article 4, Section V of the ASME Code. When an alternative calibration block or a new conventional block is used, a ratio between the DAC curves obtained from the original block and from the new block should be noted (for reference) to provide for a meaningful comparison of previous and current data.

The calibration side-drilled holes in the basic calibration block and the block surface should be protected so that their characteristics do not change during storage. These side-drilled holes or the block surface should not be modified in any way (e.g., by polishing) between successive examinations. If the block surface or the calibration reflector holes have been polished by any chemical or mechanical means, this fact should be recorded.

3. EXAMINATION

The scope and extent of the ultrasonic examinations should comply with IWA-2000, Section XI of the ASME Code.

If electronic gating is used to define the examination volume within which indications are recorded, the start and stop control points should include the entire required thickness including the material near each surface. If a single gate is used, it should be capable of recording multiple indications appearing in the gate. Alternative means of recording may be used provided they do not reduce flaw detection and recording capability.

Examination should be done with a minimum 25 percent scan overlap based on the transducer element size.

3.1 Internal Surface

The capability to effectively detect defects at the internal clad/base metal interface shall be considered acceptable if the examination procedure(s) or technique(s) meet the requirements of Section 6.0 of this document and demonstrate the following:

a. Procedures for examination from the outer surface, or when using full vee from the inside surface, should include the use of the 2 percent notch which penetrates the internal (clad) surface of the calibration blocks, defined by Section XI, Appendix I, Figure I-3131 or Section V, Article 4, Figure T-434.1. Procedures for examination from the internal surface when not using the full vee should conform to paragraph 3.1.b. below.

b. An alternate reflector, other than the 2 percent notch described above may be used provided: 1) that it is located at the clad /base metal interface or at an equivalent distance from the surface, 2) that it does not exceed the maximum allowable defect size, and 3) that equivalent or superior results can be demonstrated.

c. The examination procedure(s) should provide for volumetric examination of at least one inch of metal as measured perpendicular to the nominal location of the base metal-cladding interface.

3.2 Scanning Weld-Metal Interface

The beam angles used to scan welds should be based on the geometry of the weld/parent metal interface. Where feasible for welds such as those identified in Section T-441.4.2 of Article 4, Section V of the ASME Code, at least one angle should be such that the beam is per-

pendicular (± 15 degrees to the perpendicular) to the weld/parent metal interface, or it should be demonstrated that unfavorably oriented planar flaws can be detected by the UT technique being used. If this is not feasible, use of alternative volumetric NDE techniques, as permitted by the ASME Code, should be considered.

4. BEAM PROFILE

(Delete entire paragraph. This section included in Recommended Change 1.2.f., Angle Beam Profile Characterization.)

5. SCANNING WELD-METAL INTERFACE

(Delete entire paragraph. This section included in Recommended Change 3.2, Scanning Weld-Metal Interface.)

6. RECORDING AND SIZING

The capability to detect, record and size the flaws delineated by Section XI, IWB-3500 should be demonstrated. The measurement tolerance established should be applied when sizing flaws detected and recorded during scanning (see paragraph 7.a.).

6.1 Geometric Indications

Indications determined to be from geometric sources need not be sized. Recording of these indications should be at 50 percent DAC. When indications are evaluated as geometric in origin, the basis for that determination should be described. After recording sufficient information to identify the origin of the geometric indication, further recording and evaluation are not required.

6.2 Indications with Changing Metal Path

a. Indications that change metal path distances (indicating through-wall dimension) when scanned in accordance with the requirements of ASME Section XI, for a distance greater than that recorded from the calibration reflector should be recorded.

b. Reflectors which are at metal paths representing 25 percent and greater of the through-wall thickness of the vessel wall measured from the inner surface should be recorded in accordance with the requirements of ASME Section XI and characterized at 50 percent DAC.

c. Reflectors which are within the inner 25 percent of the throughwall thickness should be recorded at 20 percent DAC. Characterization should be in accordance with the demonstrated methods under paragraph 6.0. Where the indication is sized at 20 percent DAC, this size may be corrected by subtracting the beam width in the through-thickness direction obtained from the calibration hole (between 20 percent DAC points) which is at a depth similar to the flaw depth. If the indication exceeds 50 percent DAC, the length should be recorded by measuring the distance between 50 percent DAC levels. The determined size should be the larger of the two.

6.3 Indications without Changing Metal Path

a. Indications which do not change metal path distance when scanned in accordance with the requirements of ASME Section XI and are within the outer 75 percent of the through-wall dimension should be recorded when any continuous dimension exceeds one inch.

b. If the indication falls within the inner 25 percent of the through-wall dimensions, it should be recorded at 20 percent DAC and evaluated at 50 percent DAC.

c. Precautionary note: Indications lying parallel to welds may appear as nontraveling (without changing metal path) when scanned by parallel moving transducers whose beams are aimed normal to the weld, ie. at 90°. Multiple scans, however, may reveal that these indications are traveling indications. If so, recording and sizing are to be done in accordance with paragraph 6.2.

6.4 Additional Recording Criteria

The following information should also be recorded for indications that are reportable according to this regulatory position:

a. Indications should be recorded at scan intervals no greater than one-fourth inch.

b. The recorded information should include the indication travel (metal path distance) and the transducer position for 20 percent, (where applicable), 50 percent, and 100 percent DAC and the maximum amplitude of the signal.

c. When multi-channel equipment is used in the examination system such that all examination displays are not available for simultaneous viewing, an electronic gating system should be used which will provide on-line reproducible, recorded information, regarding metal path, amplitude and position of all indications exceeding a preset level. The preset level should be the minimum recording level required. To ensure that all recordable indications are recorded, a preferred method would incorporate multi-gates in each channel or a single gate for each channel with multi-indication recording capability.

7. REPORTING OF RESULTS

Records obtained while following the recommendations of regulatory positions 1.2, 3, and 6, along with discussions and explanations, if any, should be kept available at the site. If the size of an indication, as determined in regulatory positions 6.2 or 6.3, exceeds the allowable limits of Section XI of the ASME Code, the indications should be reported as abnormal degradation of reactor pressure boundary in accordance with the recommendation of regulatory position 2.a(3) of Regulatory Guide 1.16.

Along with the report of ultrasonic examination test results, the following information should also be included:

a. The best estimate of the tolerances in sizing the flaws at the sensitivity required in Section 6 and the basis for this estimate.

This estimate may be determined in part by the use of additional reflectors in the basic calibration block.

b. A description of the technique used to qualify the effectiveness of the examination procedure, including, as a minimum, material, section thickness and reflectors.

c. The best estimate of the portion of the volume required to be examined by the ASME Code that has not been effectively examined such as volumes of material near each surface because of near-field or other effects, volumes near interfaces between cladding and parent metal, volumes shadowed by laminar material defects, volumes shadowed by part geometry, volumes inaccessible to the transducer, volumes

affected by electronic gating, and volumes near the surface opposite the transducer.[10]

Sketches and/or descriptions of the tools, fixtures and component geometry which contribute to incomplete coverage should be included.

d. Provide sketches of equipment (i.e., scanning mechanism and transducer holders) with reference points and necessary dimensions to allow a reviewer to follow the equipment's indication location scheme.

e. When other volumetric techniques are used, a description of the techniques used should be included in the report.

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[10]It should be noted that the licensee is required to apply for relief from impractical ASME Code requirements according to §50.55a of 10 CFR. If the licensee is committed to examine a weld as per the inspection plan in the plant SAR, the licensee is required to file an amendment when the commitments made in the SAR cannot be met.

VALUE/IMPACT STATEMENT

1. PROPOSED ACTION

1.1 Description

The present inservice examination procedures for ultrasonic examination require improvement in order to consistently and reliably characterize flaws in reactor pressure vessel (RPV) welds and RPV nozzle welds. The apparent low level of the reproducibility of detection, location, and characterization of flaws leads to lengthy discussions and delays in the licensing process. Much attention is paid to the integrity of RPV welds during the licensing process because the failure probability of a reactor pressure vessel is considered to be sufficiently low to exclude it from consideration as a design basis accident. The assumption of a low probability relies heavily on regularly repeated inservice examination by ultrasonic testing (UT) of welds.

1.2 Need for Proposed Action

As more reactors start producing power, as those in operation grow older, and as more inservice examinations are performed, the number of detected flaws with uncertain characteristics (size, orientation, and location) is likely to increase. Flaw characterization is essential for flaw evaluations required by the ASME Code and by NRC to determine the structural integrity of nuclear reactor components when such flaws exist. It is essential to have valid background data for the flaw evaluations required by Section XI of the ASME Code. Based on the information gathered according to ASME Code requirements, it is often difficult to assess whether or not the flaw has grown between examinations. The procedures now in use do not require the recording of certain information that can be important in later analysis for determining the location, dimensions, orientation, and growth rate of flaws.

The lack of standardization in the use of UT equipment and procedures leads to uncertainty concerning the results obtained. For example, transducer characteristics such as beam spread, damping characteristics, and frequency for peak response are not defined, and there is no provision to keep track of these from one examination to the other. Similarly, characteristics of other UT system components such as the pulser, receiver, amplifier, and video display screen may vary from one examination to another, and all these characteristics can influence the magnitude of the flaw indications. Therefore, well-defined criteria for supplementary UT procedures are needed so that it will be possible to correctly characterize flaws, estimate flaw growth, and have reproducible results from inspections performed at different times using different equipment.

In many instances, the rate of flaw growth can be even more important than the flaw size. For example, if a flaw is found in an RPV nozzle or belt-line region and it can be demonstrated without doubt that the flaw will not grow and has not been growing, a rather large flaw can be tolerated. Crack initiation and growth is also a potential problem in cases where it is probable that no crack exists, but where there is a cluster of small rounded inclusions. These clusters of inclusions should be monitored by UT to ensure absence of cracks and crack growth.

Where the rate of flaw growth is expected to be large or is uncertain, even a small flaw may be of concern. To permit determination of growth rate, the UT procedures should be such that results of successive UT examinations can be compared. With present procedures, these results cannot be compared because of variation in instrument system characteristics. UT instrument system characteristics depend on the characteristics of the system's different components. Variation in the characteristics of calibration blocks can also affect results.

Guidelines are needed so that uncertainties in flaw characterization may be reduced or eliminated. The safety of the components is evaluated with the help of fracture mechanics. Flaw sizes need to be known for fracture mechanics evaluations. Uncertain determination of flaw sizes leads to uncertainties in the determination of the safety of the components. Uncertainties in component safety lead to delays in licensing. There is a need to specify and standardize the performance required of most UT system components to achieve better consistency in UT results so that delays in the licensing process may be reduced.

This guide will provide supplementary procedures with the objective of improving conventional UT procedures, as defined in the ASME Code. This guide is based partly on the information available in literature concerning both U.S. and European procedures and partly on the judgment of the NRC staff and their consultants. On the basis of support work being performed at the Oak Ridge National Laboratory, the staff plans to issue a revision to this guide that should further improve flaw characterization.

The use of new techniques such as holography or synthetic aperture imaging of flaws by UT that have not been implemented into practice and could considerably increase the cost of inservice examination is not being proposed here.

1.3 Value/Impact of Proposed Action

1.3.1 NRC

Reporting UT examination results as indicated in this guide would help the NRC staff and their consultants to better assess the results of the data. At present, the NRC staff must spend a great deal of time on controversy over determining the safety of components from inconsistent UT results. Lack of faith in flaw size determination from uncertain UT results points toward the adoption of some

conservative safety measures that are undesirable, for the most part, to the industry managers. Licensing delays occur because decisions have to be made on the basis of uncertain information. Flaw size determination from consistent UT results would help remove or reduce the uncertainties and debates over the safety issues. Because of the above, NRC staff time for review of reported data and interpretation of indications is likely to be reduced.

1.3.2 Other Government Agencies

Not applicable, unless the government agency is an applicant, such as TVA.

1.3.3 Industry

The value/impact on industry of the regulatory guide positions is stated by each position in the appendix to this value/impact statement. Some highlights of the value and impact of the regulatory guide positions are stated below.

1.3.3.1 Value. This regulatory guide specifies supplementary procedures that will lead to the following advantages:

a. Attaining greater accuracy and consistency in flaw characterization.

b. Providing information for consistent flaw characterization at NRC review time and thus reducing NRC staff effort in review of flaw indications.

c. Helping assess flaw growth.

d. Providing a more reliable basis for flaw detection and evaluation, which should help in the uniform enforcement of rules and the avoidance of delay in licensing decisions.

e. Reducing licensing time for reviewing examination results, which will aid in the reduction of reactor downtime during examinations and will be of great benefit to industry. With present construction costs of about 1.3 billion dollars for a 1000-megawatt reactor and the average size of a reactor running around 1100-megawatt capacity, the savings per day by eliminating reactor downtime are likely to be $500,000 or more.

f. Avoiding unnecessary repairs due to flaw size uncertainties.

g. Reducing radiation exposure to personnel by helping to eliminate unnecessary repairs. The radiation exposure during repairs is usually many times the exposure during examination, so a net reduction in radiation exposure is expected.

h. Reducing margins of error in estimates of flaw growth and thus helping reduce overconservative estimates and decisions on flaw acceptance.

i. Providing more consistent UT procedures for flaw characterization, thereby leading to procedures that ensure lower probability of missing large flaws and ensuring greater safety for the public, industrial workers, and government employees.

1.3.3.2 Impact. There will be major impact in the following three areas:

a. Quality control of the UT equipment

At present, requirements in the ASME Code for quality control of UT equipment are marginal; for example, there are no direct requirements to control the quality of UT transducers. Criterion XII, "Control of Measuring and Test Equipment," of Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants," to 10 CFR Part 50 requires, in part, that measures be established to ensure that instruments used in activities affecting quality are properly controlled, calibrated, and adjusted at specified periods to maintain accuracy within necessary limits. The recommendations of this guide will help to bring about uniformity in the quality control procedures among different companies and will ensure that quality control measures are taken to ensure reliability and reproducibility of UT results. No new UT equipment will be needed to follow the recommendations of this guide. However, the quality control measures recommended for UT equipment will impose extra cost burdens that are difficult to estimate without feedback from industry.

b. Increase in examination time

This guide would recommend, for the first time, that indications with significant length of indication travel (larger than the standard calibration holes) or with significant depth dimensions be recorded. It is not expected that the slag type of flaws, which are common among welds, or geometric reflectors will give significant traveling indications within the guidelines proposed. Hence, no substantial increase in recorded indications as a result of this recommendation is expected; however, the exact increase is difficult to predict or estimate.

Reporting of indications associated with flaws larger than 1 inch (indications larger than 1 inch plus beam spread at 20 percent DAC level) is also new. RPV welds are examined by radiography, and no flaws larger than three-quarters of an inch are acceptable in these welds. Because of this acceptance length, only new service-induced flaws larger than 1 inch, of which there should not be many, are expected to be identified and reported as a result of this recommendation.

Because of the above two new reporting recommendations, there may be an increase in examination time and dollar cost that is difficult to estimate. This will depend on how many significant flaws are detected and how large and complex they are.

c. Radiation exposure

Recommendations of this guide apply to the examination of RPV welds and RPV nozzle welds. RPV welds are usually examined by automated equipment, and data are collected on tape. Therefore, no increase in radiation exposure is anticipated as a result of the regulatory guide positions addressing RPV weld examinations.

RPV nozzle welds are sometimes examined by automated equipment but in most cases by manual UT. An increase in radiation exposure to examination personnel may be expected while RPV nozzles are being manually examined. The probable percent increase in examination time or radiation exposure is impossible to estimate without field data and research effort. Requirements for reporting traveling indications and indications associated with flaws larger than 1 inch may lead to an increase in occupational exposure in those cases in which the above indications are found and additional examination is required. The magnitude of this additional exposure can only be assessed on a case-by-case basis. It should be noted that radiation levels at vessel nozzle regions are reported to range from 0.5 to 2.0 rem/hour. Total person-rem doses can be drastically reduced by shielding and local decontamination.

The guide is not expected to have any adverse impact on other government agencies or the public.

1.3.4 Public

No impact on the public can be foreseen. The only identifiable value is a slight acceleration in the review process.

1.4 Decision on Proposed Action

The Office of Nuclear Reactor Regulation (NRR) has stated the need for this guide to help them and their consultants in evaluating the size and significance of the flaws detected during inservice examination to ensure the integrity of reactor pressure vessels between periods of examination. It would therefore be advisable to issue this guide.

2. APPROACH

2.1 Technical Alternatives

Alternatives would include requiring the use of holography, synthetic aperture imaging, acoustic emission, neutron radiography, or a combination of the above during RPV inservice examination.

2.2 Procedural Alternatives

One alternative is to leave the situation as it is. A second alternative is to request change of the ASME Code requirements.

2.3 Comparison of Technical Alternatives

Imposing inservice examination of RPV welds by the use of holography, synthetic aperture imaging technique, or acoustic emission, all of which are still in the stage of prototype development and have not been proved effective for field use, would not be justifiable on the basis of either cost or effectiveness.

2.4 Comparison of Procedural Alternatives

Leaving the situation as it is would mean that continued attention and manpower would have to be devoted by the NRC staff to investigate the uncertainties associated with flaw growth on a case-by-case basis. The low level of confidence in the present techniques means that excessive margins would continue to be used in the flaw-acceptance criteria. Also, unnecessary cutting and repair attempts to remove suspected flaws may result.

The procedures recommended in this guide have been shown to be effective in practice, although they are not in general use in the United States. Including these procedures as regulatory guide recommendations should result in their wider use and consequently their improvement. After these procedures have been accepted by the industry, we will seek their inclusion in the ASME Code. Some of these procedures have already been sent to the ASME for consideration and inclusion in the present ASME Code procedures for ultrasonic examinations.

2.5 Decision on Technical and Procedural Alternatives

On the basis of the above, it appears desirable to issue a regulatory guide to provide recommendations for improving ASME Code procedures. These recommendations, which are based on the advanced state-of-the-art UT procedures in current use by some organizations, would improve the ability to detect and characterize flaws without imposing new, unproved techniques for flaw detection on industry.

3. STATUTORY CONSIDERATIONS

3.1 NRC Authority

The authority for this guide is derived from the safety requirements of the Atomic Energy Act of 1954, as amended, and the Energy Reorganization Act of 1974, as implemented by the Commission's regulations. In particular, § 50.55a, "Codes and Standards," of 10 CFR Part 50 requires, in part, that structures, systems, and components be designed, fabricated, erected, constructed, tested, and inspected to quality standards commensurate with the importance of the safety function to be performed.

3.2 Need for NEPA Assessment

The proposed action is not a major action, as defined by paragraph 51.5(a)(10) of 10 CFR and does not require an environmental impact statement.

4. RELATIONSHIP TO OTHER EXISTING OR PROPOSED REGULATIONS OR POLICIES

Recommendations of this guide would be supplemental to the requirements of Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components," of the ASME Code, which is adopted by § 50.55a, "Codes and Standards," of 10 CFR Part 50.

5. SUMMARY

This guide was initiated as a result of a request from NRR. Preliminary results of the round robin UT examination procedures following ASME Code procedures indicate a need for additional guidelines to the existing ASME Code procedures to control equipment performance, calibration block specifications, and scanning procedures to improve the reproducibility of results and detectability of through-thickness flaws.

Minimum ASME Code requirements do not specify the details of recording requirements that are essential to evaluate flaws. This deficiency in the Code rules makes it difficult for the NRC staff or their consultants to review, analyze, and assess the UT data to determine the flaw size and evaluate the system safety when the data are made available to NRC at a later date. The present data obtained from UT equipment of uncertain and unspecified performance lead to discussions and delays in the review process resulting in loss of NRC staff time and loss of plant availability and power generation capacity for the utilities. These situations definitely need to be avoided as much as possible. This guide is aimed at achieving this purpose by issuing recommendations that will be supplementary to the existing ASME Code UT procedures. The issue remains whether to wait for the development of advanced NDE techniques and continue with the present ASME Code procedures resulting in uncertainties, delays, and discussions or to encourage improvement in the present state of the art of conventional UT. The decision appears to be obvious that we should use conventional UT based on engineering judgment until some new techniques for flaw detection and sizing can be proved effective in the field. This guide is aimed at providing the recommendations needed to improve on the ASME Code UT requirements until proven advanced NDE techniques are available.

APPENDIX TO VALUE/IMPACT STATEMENT

Values that will result from this regulatory guide are much easier to perceive than the impact. It is very difficult to assess the real impact because the kind of statistical data needed is simply not available at this time. One way in which we hope to estimate the impact is through industry feedback after the guide has been issued.

We have made an attempt, in a qualitative manner, to estimate the value/impact of regulatory guide positions, position by position, as follows:

1. INSTRUMENT PERFORMANCE CHECKS

Recording the characteristics of the ultrasonic testing (UT) examination system will be useful in later analysis for determining the location, dimensions, orientation, and growth rate of flaws. System performance checks to determine the characteristics of the UT system will be made shortly before the UT examinations. Each UT examination will therefore be correlated with a particular system performance check. This practice will help to compare results. These determinations will help make it possible to judge whether differences in observations made at different times are due to changes in instrument characteristics or are due to real changes in the flaw size and characteristics.

It is recommended that, as a minimum, instrument checks should be verified before and after examining all the welds that need to be examined in a reactor pressure vessel during one outage.

Performance of these instrument checks is likely to add a few thousand dollars to test equipment cost and to take 1 to 2 hours of examination time before and after each reactor pressure vessel (RPV) examination. The examination equipment is usually idle between examinations. Performance checks on the examination equipment could be performed during these idle periods. These performance checks are not likely to reduce the number of examinations that a particular UT system could perform in a year. No additional radiation exposure is expected because of this position.

2. CALIBRATION

According to this position, system calibration should be checked to verify the distance-amplitude correction (DAC) curve, as a minimum, before and after each RPV examination (or each week the system is in use, whichever is less) or each time any component (e.g., transducer, cable, connector, pulser, or receiver) in the examination system is changed.

Subarticle I-4230, Appendix I, Section XI, ASME B&PV Code (1974 edition), which applied to the inspection of the RPV, required calibration using the basic calibration block at "the start and finish of each examination, with any change in examination personnel and at least every 4 hours during an examination." However, the 1977 rules of Article 4 (T-433), Section V, which are referenced by Section XI and now apply to the examination of the RPV, require calibration against the calibration block only "prior to use of the system." It is considered that the present 1977 ASME Code rules are not adequate to control potential problems in the variation of instrument performance characteristics. Therefore, the recommended calibration before and after each examination is a more reliable approach to instrument performance checks. The above position is not more conservative than the previously accepted 1974 Code rules, but is more conservative if 1977 rules are considered.

Considering the requirements of Article 4, Section V (1977), the above position will mean a calibration check each week the system is in use or before and after each RPV examination, whichever is less, instead of before each examination. A calibration check against the calibration block takes 15 to 30 minutes for manual UT and for automated UT equipment where provision is made to calibrate the equipment without having to remove the transducers from the rotating scanning arm of the mechanized scanner. In some cases, transducers have to be removed from the scanning arm for calibration of the UT instrument; in these cases, a calibration check may take from 30 to 60 minutes. The added cost of the above would be in terms of additional time spent by the examiner and would occur each week or once for each RPV examination, depending on whether or not the examination is completed in less than a week. No additional radiation exposure is expected because of this position.

3. NEAR-SURFACE EXAMINATION AND SURFACE RESOLUTION

This position recommends that an estimation of the capability to effectively detect defects at the metal front and back surfaces of the actual component should be made and reported. This will not require any additional calibration or examination time but will simply require an estimate of this capability by the examiner, which will be reported to NRC. No additional radiation exposure is expected because of this position.

4. BEAM PROFILE

This position recommends that the beam profile (for each search unit used) should be determined if any significant flaws are detected during the RPV examination.

Assuming that no more than three search units are likely to be used during an RPV examination, this step is likely to require no more than 2 hours of examination time. No additional radiation exposure is expected because of this position.

5. SCANNING WELD-METAL INTERFACE

This position recommends that the beam angles used to scan welds should be based on weld/parent-metal interface

geometry and at least one of these angles should be such that the beam is almost perpendicular (±15 degrees to the perpendicular) to the weld/parent-metal interface, unless it can be demonstrated that large (Code-unacceptable) planar flaws unfavorably oriented can be detected by the UT technique.

On the basis of information available, it appears that it is difficult[1,2,3] to detect large planar flaws (e.g., service-induced fatigue or stress corrosion cracks) oriented at right angles to the surface, using the ASME Code UT procedure. However, the option is being provided to demonstrate that such flaws can be located by conventional methods or by using new advances in UT techniques. In these cases, the technique will be acceptable as a volumetric examination method. Otherwise, the use of high-intensity radiography or tandem-probe UT technique, among other techniques, should be considered.

The above type of flaw is the most significant but the most difficult to detect. Because of this, the present recommendations are being made despite their potential impact on cost and radiation exposure.

The potential impact may be as follows:

a. Additional NRC staff time may be needed to evaluate the effectiveness of UT techniques on a generic basis to detect perpendicular planar flaws. After techniques are recognized to accomplish the above, NRC staff time that is being spent currently on evaluating problems on a plant-by-plant basis is expected to be considerably reduced.

b. Reactor downtime may increase, depending on the examination time differentials between the conventional and refined techniques. This may, however, be offset by a reduction in the downtime currently needed for NRC experts to evaluate data that sometimes requires further clarification and reexamination.[2,4]

c. Additional cost might be incurred in changes needed to add transducers or data-gathering capability to existing automated equipment or to automate current manual examinations. Automation of current manual techniques is likely to reduce radiation exposure to personnel.

6. SIZING AND RECORDING OF INDICATIONS

6.1 Traveling Indications

This position recommends the recording of traveling indications. If RPV welds do not have any travel indications on the screen larger than the indication on the screen from the calibration holes (1/2-inch hole for a 12-inch weld thickness, 3/8-inch hole for an 8-inch thickness), this recommendation will not result in any more recording of indications. If the RPV welds being examined have several indications with travel in excess of the calibration hole diameter, the examination and recording time will be increased for the investigation of these flaws, depending on the number of these indications. Slag inclusions in welds are generally long cylindrical defects and do not have much depth unless they are associated with shrinkage or service-induced cracks. These slag inclusions are not expected to increase the number of indications that will be recorded. Increase in examination time will depend on the number, size, and complexity of geometry of through-thickness indications.

For RPV girth or nozzle welds where examination is performed by automated equipment and data are recorded on tape, this position will mean no increase in examination time or radiation exposure; but interpretation, analysis, and reporting time for these depth indications will increase. The extra burden in terms of dollar cost will depend on the number, size, and complexity of flaws, and there are no rational bases or data available at this time to estimate the increase in the cost of examination.

For RPV welds, mostly nozzle welds, where examination is performed manually and data are not recorded on tape, this position will mean extra examination time and increased radiation exposure to the examiners. Increase in dollar cost and radiation exposure will again depend on the number, size, and complexity of indications, and there are no bases or data available to estimate this increase.

6.2 Nontraveling Indications

This position also recommends the recording of nontraveling indications above 20 percent DAC level that persist for a distance of more than 1 inch plus the beam spread. According to NB-5320, Radiographic Acceptance Standards, Section III, Division 1, ASME Code, 1977 edition, flaws larger than 3/4 inch for weld thicknesses above 2-1/4 inches are not acceptable. Because of this requirement, it is expected that no flaws larger than 3/4 inch in length are present in the RPV welds, and if indications are detected that suggest flaws larger than 3/4 inch, there is a strong possibility that these may be service-induced flaws. Service-induced flaws are rare in RPV welds, and it is therefore not expected that additional indications would have to be recorded because of this position. However, if such indications (over 1 inch) are detected, examination time for automated recording and examination time plus radiation exposure for manual UT examinations will be increased. There are no rational bases or data available to estimate the impact of regulatory position 6.2.

7. REPORTING OF RESULTS

This position recommends that the areas required to be examined by the ASME Code that have not been effectively examined and an estimate of error band in sizing the flaws

[1] "Probability of Detecting Planar Defects in Heavy Wall Welds by Ultrasonic Techniques According to Existing Codes," Dr. Ing. Hans-Jurgen Meyer, Quality Department of M.A.N., Nurnberg, D 8500 Nurnberg 115.

[2] "Interim Technical Report on BWR Feedwater and Control Rod Drive Return Line Nozzle Cracking," NUREG-0312, July 1977, p. 3.

[3] "Analysis of the Ultrasonic Examinations of PVRC Weld Specimens 155, 202, and 203," R.A. Buchanan, Pressure Vessel Research Committee (PVRC) Report, August 1976.

[4] "Summary of the Detection and Evaluation of Ultrasonic Indications - Edwin Hatch Unit 1 Reactor Pressure Vessel," January 1972, Georgia Power Company.

should be brought to the attention of the NRC when the results are reported. This effort may take about 5 hours in report writing time.

8. IMPLEMENTATION

It should be noted that the recommendations of this guide are not intended to apply to those preservice examination tests already completed. However, the licensees may consider repeating their preservice examination tests or using the recommendations of this guide any time at their option to avoid possible flaw interpretation problems at a later date. Flaw interpretation problems may occur if traveling indications identified as significant according to the recommendations of this guide do not correlate with preservice volumetric NDE results and hence would be assumed to have been service induced. It would be difficult to show that these indications arose from fabrication flaws. Therefore, licensees would be well advised to consider the above possibilities.

8.1 Alternatives

The following alternatives were considered in applying the recommendations of this guide.

1. To apply the recommendations of the guide to all the preservice and inservice examinations that have already been performed.

2. To apply the recommendations of the guide to all future preservice and inservice examinations performed after the issuance of the guide.

8.2 Discussion of Alternatives

8.2.1 First Alternative

Alternative 1 would infer that all RPV welds examined as per the current code requirements are at a quality level that would not ensure an acceptable safety performance. This approach would also mean that all the plants would have to repeat, in accordance with the recommendations of this guide, those inservice and preservice examinations performed in the past. Such a policy would tend to be overly conservative and would put a heavy burden on all plant owners. Although UT examinations have missed some flaws in the past, there appears to be no immediate danger from the estimated flaw distribution probability to warrant such a strong action. Therefore, this alternative was not adopted.

8.2.2 Second Alternative

In the past, several instances have been noted where the minimal Code UT examination procedures have not been adequate for detecting and sizing flaws. Discussions and undesirable licensing delays were frequently the result. As more plants begin producing power and existing plants grow older, more flaws may be expected in the weld areas. These flaws may be generated as a result of fatigue, stress corrosion, or other unanticipated factors. It is imperative that the guide recommendations for supplementary UT examination procedures be used in the future to maintain an acceptable level of safety at these welds. The second alternative was therefore selected for applying this guide to the preservice and inservice examination of RPV welds.

It is expected that inservice UT examinations will detect flaws generated during plant operation, whereas preservice examinations will provide UT examination data for subsequent comparisons. First, a radiographic examination is performed of all the vessel welds under Section III of the ASME Code. After this examination, a UT preservice examination of welds is performed to serve as a supplementary volumetric examination. Because of the above, these preservice examinations are not as important as inservice examinations. It was therefore decided that the guide recommendations should apply to judging the inservice examination results for those examinations performed immediately after the issuance of the guide; however, the guide recommendations should apply to preservice examinations beginning 6 months after the issuance date. The NRC staff considered this approach best because of the difficulties being experienced in reviewing inservice UT examination data from the different plants.

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