U.S. NUCLEAR REGULATORY COMMISSION
OFFICE OF STANDARDS DEVELOPMENT
DRAFT REGULATORY GUIDE AND VALUE/IMPACT STATEMENT

May 1979
Division 1
Task SC 705-4

ULTRASONIC TESTING OF REACTOR VESSEL WELDS DURING INSERVICE EXAMINATION

A. INTRODUCTION

FOR COMMENT

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 ASME 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.

This regulatory guide and the associated value/impact statement are being issued in draft form to involve the public in the early stages of the development of a regulatory position in this area. They have not received complete staff review, have not been reviewed by the NRC Regulatory Requirements Review Committee, and do not represent an official NRC staff position.

Public comments are being solicited on both drafts, the guide (including any implementation schedule) and the value/impact statement. Comments on the value/impact statement should be accompanied by supporting data. Comments on both drafts should be sent to the Secretary of the Commission, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555, Attention: Docketing and Service Branch, by AUG 6 1979

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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 requirements concerning record retention such as duration, location, and assigned responsibility.

This guide describes procedures acceptable to the NRC staff on an interim basis for implementing the above requirements with regard to the preservice and inservice examination of reactor vessel welds in light-water-cooled nuclear power plants. 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 large flaws be reliably detected and evaluated. It is desirable that results may be compared from one ultrasonic testing (UT) examination to the other so that flaw growth rates may be estimated. Lack of reliability of UT examination results is partly due to the reporting of ambiguous results. Reporting of UT indications as recommended in this guide will help to provide a means for assessing the ambiguity of the reported data.

Operating and licensing experience[1,2,3] and industry tests[4] have indicated that UT procedures that have been used for examination 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 PERFORMANCE CHECKS

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.

System performance checks to determine the characteristics of the UT system should be performed at intervals close enough that each UT examination may 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 instrument characteristics or are due to real changes in the flaw size and characteristics.

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

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[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.

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. This periodic check has been extended from 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. Stability of automated electronic equipment is dependent on many factors, and the ASME Code has no quality standards on the components of these systems. Until stability of performance of UT systems can be ensured by the introduction of quality standards for all components, it is not reasonable to increase the period between calibration checks. Therefore, recommendations have been made to check instrument characteristics more frequently than 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 hr. during the examination and when examination personnel are changed."

This requirement has several minor deficiencies, including the following:

a. Calibration check is now required on only one of the basic reflectors. As a result, the accuracy of only one point on the Distance-Amplitude Correction (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. The change allows a one-point check by a mechanical or electronic simulator instead of a check against the basic calibration block. A mechanical

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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 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. 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 of these provisions may introduce errors that will be very difficult to detect for the following reasons:

(1) The simulator and its application are not defined. Neither are the electronics parameters or their required stability specified. Until the above parameters are defined and the pulse voltage is checked against a standard source of reference, the electronic simulator should not be used.

(2) Checking the transducer sensitivity separately neglects the effects of broken chips, variation in epoxy contact bond, and transducer pressure against the component, which affects coupling and variations or faults in coupling connectors. Until guidance is provided to avoid the effect of these variables, it is not advisable to check the transducer sensitivity separately.

d. Calibration Checks

(1) Scanning Speed. The resolution capability of UT systems may be dependent on the scanning speed because of the (a) increase in tracking motor vibrations for automated equipment and (b) variations in contact force and hence coupling efficiency between the transducer and the metal. These resolution capability differences may introduce errors when the calibration is done by a hand-held static transducer and scanning is performed by automated equipment, or during a manual scan when the calibration is done with a static transducer and scanning for flaw detection is through a moving transducer.

For the above reasons, calibration should be performed by a moving transducer when the reference DAC curve is to be used for the detection of flaws. For flaw sizing by the manual method, static calibration may be used if sizing is performed using a static transducer. To minimize the effect of any vibrations, the scanning speed should not exceed the calibration speed when automated equipment is used. For automated equipment, the scanning direction should be the same as the calibration direction, unless it can be shown that change of scanning direction does not make a difference in the sensitivity and vibration background noise received from the search unit, or these differences should be taken into account. Some search units have a curved shoe that tends to heel over when the scanning direction is changed, thereby resulting in loss of received signal.

(2) Secondary DAC. During some manual scans, the end point of the DAC curve may fall below 20% of the full screen height. When this happens, it is difficult to evaluate flaws on the 20% and 50% DAC basis in this region since the 20% and 50% 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% and 50% 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% of screen height.

(3) 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.

(4) 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 calibr lock depend on, among other things, the surface roughness of the block and 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 directional sound beam pattern, and hence the flaw is more difficult to detect and size.[5] Therefore, 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 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° is not recommended. Two factors would make the use of shear wave angles close to 75° 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 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

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

the entire volume of the weld and adjacent base metal. Any area where a reduction of the normal back-surface reflection amplitude exceeds 50% 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 of these large flaws may not reflect much energy to the search unit.[5] Because of this possibility, the depth dimension of the flaw should be more 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% DAC as well as at 50% 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% 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% 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% DAC; hence, beam spread has to be considered in judging the significance of flaws.[6] It is therefore recommended that only signals with a total transducer travel movement greater than the beam spread should be considered significant.

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

7. REPORTING OF RESULTS

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 material volume near each surface or volumes shadowed by part geometry, are not effectively examined. The volumes of material that are not effectively examined depend on the particular part geometry and unique situations associated with each reactor pressure vessel. 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, supplemented by the following:

1. INSTRUMENT PERFORMANCE CHECKS

The checks described in paragraphs 1.1 through 1.4 below 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

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Code-allowable criteria. As a minimum, these checks should be verified before and after examining all the welds that need to be examined in a reactor pressure vessel during one outage.

1.1 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, with the same setting of pulse-shape modification and noise-suppression controls as used during examination and in the same range of the instrument as the range that would actually be used during examination. For systems using an electronic DAC, a means should be devised and used for demonstrating the proportionality of the signal response to different sizes of reflectors at 1/4, 1/2, and 3/4 T depth. The accuracy of the proportionality should be recorded.

1.2 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.

1.3 Frequency-Amplitude Curve

A photographic record of the frequency-amplitude curve should be obtained; as a minimum, when a camera is not available, the peak frequency value and points 3 dB, 6 dB, and 12 dB below peak frequency amplitude should be recorded. 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.

1.4 Pulse Shape

A photographic record of the unloaded initial pulse should be obtained against a calibrated time base. 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 reactor pressure vessel 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 inservice examinations of the same reactor pressure vessel. 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 these calibration reflector holes or the block surface is polished by any chemical or mechanical means, this fact should be recorded.

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, "Reporting of Operating Information--Appendix A Technical Specifications." 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, for determining beam spread. Beam profile curves should be determined for each of the holes in the basic calibration block.

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 large (Code-unacceptable) planar flaws unfavorably oriented, parallel to the weld-metal interface, can be detected by the UT technique being used. Otherwise, use of alternative volumetric nondestructive examination (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. Beam angles used for UT examination 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.

6. SIZING

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% amplitude) should be recorded. Indications that travel should be recorded and sized at 20% DAC. Where the indication is sized at 20% DAC, this size may be corrected by subtracting for the beam width in the through-thickness direction obtained from the calibration hole (between 20% DAC points) that is at a depth similar to the flaw depth. If the indication exceeds 50% DAC, the size should be recorded by measuring the distance between 50% 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% DAC level that persist for a scanning distance of more than 1 inch plus the beam spread between 20% DAC points (as defined by the 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% DAC and between points at 20% DAC where the beam-width correction is made only for the 20% DAC size. The recorded size of the flaw would be the larger of the two determinations.

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 of an inch.

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

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7. REPORTING OF RESULTS

Records obtained while following the recommendations of regulatory positions 1.1, 3, 5, and 6 above, along with discussions and explanations, if any, should be reported with the examination test results to NRC. 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 B&PV Code, the indications should be reported as abnormal degradation of reactor pressure boundary in accordance with the recommendations 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 volume that has not been effectively examined out of the volume required to be examined by the ASME Code 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 to the transducer should be given.

c. If considered desirable, 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.

D. IMPLEMENTATION

This proposed guide has been released to encourage public participation in its development. 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 to be described in the active guide reflecting public comments will be used in the evaluation of (1) the results of inservice examination programs of all operating reactors performed after issuance of the active guide and (2) the results of preservice examination programs of all reactors under construction performed 6 months after issuance of the active guide.

The recommendations of this guide are not intended to apply to preservice examinations that have already been completed.

After the issuance of the active guide, the NRC staff intends to recommend that all licensees consider modifying their technical specifications so that they are consistent with the recommendations contained therein.

DRAFT VALUE/IMPACT STATEMENT

1. PROPOSED ACTION

1.1 Description

The present inservice examination ultrasonic testing (UT) procedures for flaw detection require improvement in order to consistently and reliably characterize flaws in the current 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 delay in the licensing process. Great 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 rationale for this low probability relies heavily on regularly repeated inservice examination by ultrasonic testing of welds.

1.2 Need for Proposed Action

As more reactors start producing power, as those in operation grow in age, 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 that are 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 in 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 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 characterize flaws correctly, 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. This is also a potential problem for cases where it is probable that no crack exists, but there is a cluster of small rounded inclusions that must be monitored by flaw-growth techniques to ensure acceptable behavior.

But if the rate of flaw growth is expected to be large or is uncertain, even a small flaw may be of concern. For comparison of results to determine growth rate, the UT procedures should be such that results of successive UT examinations can be compared and flaw growth determined. With present procedures, these results cannot be compared because of variation in instrument characteristics. UT instrument characteristics depend on the characteristics of the instrument's different components, and variation in the characteristics of calibration blocks can also affect results.

Guidelines are needed so that uncertainties in the flaw characterization and resulting delays in the licensing process may be reduced. There is a need to specify and standardize required performance of most UT system components to achieve better consistency in UT results.

This proposed guide will provide supplementary procedures with the objective of improving conventional UT procedures, as defined in the B&PV Code. This guide is based partially on the information available in literature on 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, which have not been introduced to 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 of UT examination results as indicated in this guide would help the NRC staff and their consultants to better assess the results of the data. 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 proposed 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 proposed regulatory guide positions are stated below.

1.3.3.1 Value. The proposed regulatory guide is a scheduled milestone in the technical activity of Task A-14 as defined by NRR and 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 tend to avoid 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 elimination of 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 for missing large flaws and ensuring greater safety for the public, industrial workers, and other 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% 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 picked up 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 man-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 Division of Operating Reactors, 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 proposed guide for comment.

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, which are still in the stage of prototype development and which 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 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 will 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 flaw detectability and characterization without imposing new unproved techniques for flaw detection on industry.

3. STATUTORY CONSIDERATIONS

3.1 NRC Authority

This guide would fall under the authority and safety requirements of the Atomic Energy Act. In particular under §50.55a, "Codes and Standards," of 10 CFR Part 50, which 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 10 CFR 51.5(a)(10), 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 proposed guide was initiated as a result of a request from the Division of Operating Reactors, NRR. It forms a part of Task A-14, as defined by NRR, and is identified as a milestone in the technical activity of Task A-14. 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, and scanning procedures to get better 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, 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 often 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 optimize 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 proposed 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 DRAFT VALUE/IMPACT STATEMENT

Values that will result from this proposed regulatory guide are much easier to perceive than the impact, which is very difficult to assess because the kind of statistical data needed to determine the real impact 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 for comment.

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 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 ultrasonic testing (UT) system will be made at intervals close enough that each UT examination may be correlated with a particular system performance check. This 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 RPV examination. By estimating the examiner's salary to be about $50 per hour, these checks should not cost more than $100 each time they are performed. The use of the examination equipment is seldom scheduled so close that there is not even a few hours between examinations; therefore, the idle time on the equipment is not likely to increase, and hence the cost differential of insurance and depreciation on the equipment has not been included in the above calculations. 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 reactor pressure vessel (RPV) examination (or each week the system is in use, whichever is less) or each time any component (e.g., transducer, cable, connnector, pulser, or receiver) in the examination system is changed.

Up to the Summer 1975 Addenda, Subarticle I-4230, Appendix I, Section XI, ASME B&PV Code, which applied to the inspection of the RPV, required calibration using the basic calibration block each 4 hours. However, the present (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 a ratchet on previously accepted 1975 Code rules on this item but is a ratchet 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. Calibration check against the calibration block takes 15 to 30 minutes for manual UT and 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, calibration check may take from 30 to 60 minutes. The added cost of the above may range from $25 to $50 in terms of additional time spent by the examiner. This cost is calculated using a $50 per hour wage rate 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. This may take 4 hours of effort and may cost around $200 for each RPV examination report sent to NRC. This calculation is based on assuming $50 per hour wages for the examiner. 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. Therefore, this beam profile determination should cost no more than $100 for each RPV examination based on a $50 per hour wage rate. 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[7,8,9] 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 should be considered, among others.

The above type of flaws is the most significant yet 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. Extra 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 reduced considerably.

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 needed currently to evaluate data by NRC experts on a case-by-case basis that sometimes require further clarifications and reexaminations.[8,10]

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[7] "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., Nürnberg, D 8500 Nürnberg 115.

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

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

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

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 indications in the welds whose travel indication on the screen is larger than the indication on the screen from the calibration holes (1/2" hole for 12" weld thickness, 3/8" hole for 8" 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 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 is no rational basis or data available at this time to estimate the increase in 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 depend again on the number, size, and complexity of indications, and there is no basis or data available to estimate this increase.

6.2 Nontraveling Indications

This position also recommends the recording of nontraveling indications, above 20% 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 I, ASME B&PV Code, 1977 edition, flaws larger than 3/4 of an 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 of an inch in length are present in the RPV welds, and if indications are detected that suggest flaws larger than 3/4 of an 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 is no rational basis or data available to estimate the impact of this part (6.2) of this regulatory position.

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 should be brought to the attention of the NRC when the results are reported. This effort will take about 5 hours in report-writing time. The dollar cost for this effort is estimated to be $250 based on a $50 per hour wage rate.

IMPLEMENTATION

It should be noted that recommendations of this guide are not intended to apply to 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 arise from fabrication flaws. Therefore, the licensees would be well advised to consider the above possibilities.

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