INTERNATIONAL

Designation: ~~E636 – 14ε1~~ E636 – 20

Standard Guide for Conducting Supplemental Surveillance Tests for Nuclear Power Reactor Vessels[1]

This standard is issued under the fixed designation E636; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

~~ε1 NOTE—The title of this guide was updated editorially in May 2017.~~

1. Scope

1.1 This guide discusses test procedures that can be used in conjunction with, but not as alternatives to, those required by Practices E185 and E2215 for the surveillance of nuclear reactor vessels. The supplemental mechanical property tests outlined permit the acquisition of additional information on radiation-induced changes in mechanical properties of the reactor vessel steels.

1.2 This guide provides recommendations for the preparation of test specimens for irradiation, and identifies special precautions and requirements for reactor surveillance operations and post-irradiation test planning. Guidance on data reduction and computational procedures is also given. Reference is made to other ASTM test methods for the physical conduct of specimen tests and for raw data acquisition.

1.3 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E23 Test Methods for Notched Bar Impact Testing of Metallic Materials
E185 Practice for Design of Surveillance Programs for Light-Water Moderated Nuclear Power Reactor Vessels
E399 Test Method for Linear-Elastic Plane-Strain Fracture Toughness K_{Ic} of Metallic Materials
E1253 Guide for Reconstitution of Irradiated Charpy-Sized Specimens
E1820 Test Method for Measurement of Fracture Toughness
E1921 Test Method for Determination of Reference Temperature, T_o, for Ferritic Steels in the Transition Range
E2215 Practice for Evaluation of Surveillance Capsules from Light-Water Moderated Nuclear Power Reactor Vessels
E2298 Test Method for Instrumented Impact Testing of Metallic Materials

2.2 *ASME Standards:*[3]

ASME Boiler and Pressure Vessel Code, Section III Subsection NB (Class 1 Components)

3. Significance and Use

3.1 Practices E185 and E2215 describe a minimum program for the surveillance of reactor vessel materials, specifically mechanical property changes that occur in service. This guide may be applied ~~in order~~ to generate additional information on radiation-induced property changes to better assist the determination of the optimum reactor vessel operation schemes.

4. Supplemental Mechanical Property Test

4.1 *Fracture Toughness Test*—This test ~~involves the dynamic or static testing~~consists of a quasi-static or dynamic test of a fatigue-precracked specimen during which a record of force versus displacement is used to determine material fracture toughness

[1] This guide is under the jurisdiction of ASTM Committee E10 on Nuclear Technology and Applications and is the direct responsibility of Subcommittee E10.02 on Behavior and Use of Nuclear Structural Materials.

Current edition approved ~~Jan. 1, 2014~~Jan. 1, 2020. Published ~~February 2014~~January 2020. Originally approved in 1983. Last previous edition approved in ~~2010~~2014 as ~~E636 – 10.~~E636 – 14ε1. DOI: ~~10.1520/E0636-14E01.~~10.1520/E0636-20.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American Society of Mechanical Engineers, 345 E. 47th St., New York, NY 10017.

properties such as the ~~plane strain fracture toughness (*K*~~*plane-strain*$_{Ic}$~~), the J-integral~~ fracture toughness (J_{Ic}), the *J-R* curve, and the Master Curve reference temperature (T_o) (see Test Methods ~~E399,~~ E1820, and E1921, respectively). These test methods generally apply to ~~elastic,~~ ductile-to-brittle transition, or fully plastic behavior. The rate of specimen loading or stress intensity increase required for test classification as quasi-static or dynamic is indicated by the referenced test methods. All three test methods specify a lower limit on loading rate for dynamic tests.

4.2 *Fracture Toughness Test at Impact Loading Rates*—This test ~~involves~~ consists of impact testing ~~of~~ Charpy-type specimens that have been fatigue precracked. A force versus deflection or force versus time record, or both, ~~is~~ can be obtained during the test to determine an estimate of ~~material~~ dynamic fracture toughness properties. Testing and data analysis shall be performed in accordance with Annex A17 of Test Method E1820.

4.3 *Instrumented Charpy V-Notch Test*—This test ~~involves the impact testing of~~ consists in testing standard Charpy V-notch specimens using a conventional impact tester (Test Methods E23) equipped with supplemental instrumentation that provides a force versus deflection or time record, or both, to ~~augment~~supplement standard test data (see Test Method E2298). The test record is used primarily to estimate dynamic yield stress, fracture initiation and propagation energies, and to identify fully ductile (upper shelf) fracture behavior.

4.4 Other mechanical property tests not covered by ASTM standards, for example, miniature, nondestructive, nonintrusive, or in-situ testing techniques, can be utilized to accommodate limitations of material availability or irradiation facility configuration, or both. However, the user should establish the method's technical validity and correlation with existing test methods.

5. General Test Requirements

5.1 *Specimen Orientation and Preparation:*

5.1.1 *Orientation*—It is recommended that specimens for supplemental surveillance testing be taken from the quarter thickness location of plate and forging materials, as defined in NB 2300 of ASME Boiler and Pressure Vessel Code, Section III, and at a distance at least one material thickness from a quenched edge. Specimens from near surface material also may be considered for special studies, if required. For weld deposits, it is recommended that the specimens be taken from a thickness location at least 12.7 mm (½ in.) removed from the root and the surfaces of the weld. Consistent with Practice E185, it is further recommended that the specimens be oriented to represent the transverse orientation (T-L, per Test Method E399) in plate and forging materials. Specimens having ~~the~~ longitudinal orientation (L-T, per Test Method E399) also may be ~~used given~~ used, provided there is sufficient material and space in the surveillance capsule. For weld deposits, the specimen shall be oriented to make the plane of fracture parallel to the welding direction and perpendicular to the weldment surface, with the direction of crack growth along the welding direction. Examples of specimen orientations are given in Fig. 1.

5.1.1.1 *Specimen Notch Orientation*—The specimen notch root in all cases shall be oriented normal to the plate, forging, or weldment surface. For weld deposits, the notch ~~also should~~ shall be located ~~at~~ as close as possible to the approximate weld deposit centerline. The centerline and the width of the weld deposit about the notch shall be determined from the weld fusion lines revealed by etching. It is recommended that the location of the weld fusion lines be permanently marked for reference for post-irradiation testing. The general appearance of the etched weld deposit in terms of individual weld bead size (large versus small) and the number of weld beads across the weld deposit ~~should~~shall be determined and recorded.

5.1.1.2 *Specimen Marking*—A suitable specimen identification, marking, and documentation system shall be used whereby the location and orientation of each specimen within the source plate, forging, or weldment can be traced. The traceability of weld specimens is particularly important because of the possibility for variations through the weldment thickness.

5.1.2 *Preparation*—All specimens shall be prepared from material that has been fully heat-treated, including stress-relief annealing, as recommended in Practice E185.

5.1.2.1 *Reconstitution*—If reconstituted specimens are ~~to be~~ used, the procedures outlined in Guide E1253 shall be followed for Charpy-sized specimens. For other specimen geometries, it must have been previously ~~proven~~demonstrated that the reconstitution procedure has no significant influence on the test result.

5.1.2.2 *Machining*—Specimens for irradiation should be finish machined on all sides to aid encapsulation in reactor experiments and to aid radiation temperature control and uniformity.

5.1.2.3 *Fatigue Precracking*—Fatigue precracking of fracture toughness specimens shall be performed in the final testing condition, including material irradiation and annealing, as required in Test Method E1820. If this is technically not practical, the procedure outlined in Test Method E1820, sections 7.4.5.1 and 7.4.5.2, shall be applied by taking into account, in addition to temperature, also the effect of irradiation and annealing on ~~material~~ the material's yield strength. If irradiation/annealing operations have been applied between specimen precracking and final testing, the parameters σ^{f}_{YS}(yield strength at precracking temperature) and σ^{T}_{YS}(yield strength at test temperature) shall ~~include~~ account for the ~~effect~~influence of irradiation/annealing in addition to the effect of temperature. The material yield strength in the precracking condition and in the test condition, as well as their temperature dependence, shall be documented in the test report. As a precaution, it is recommended to apply a value of K_{max} as low as practically feasible during precracking.

5.2 *Specimen Irradiation:*

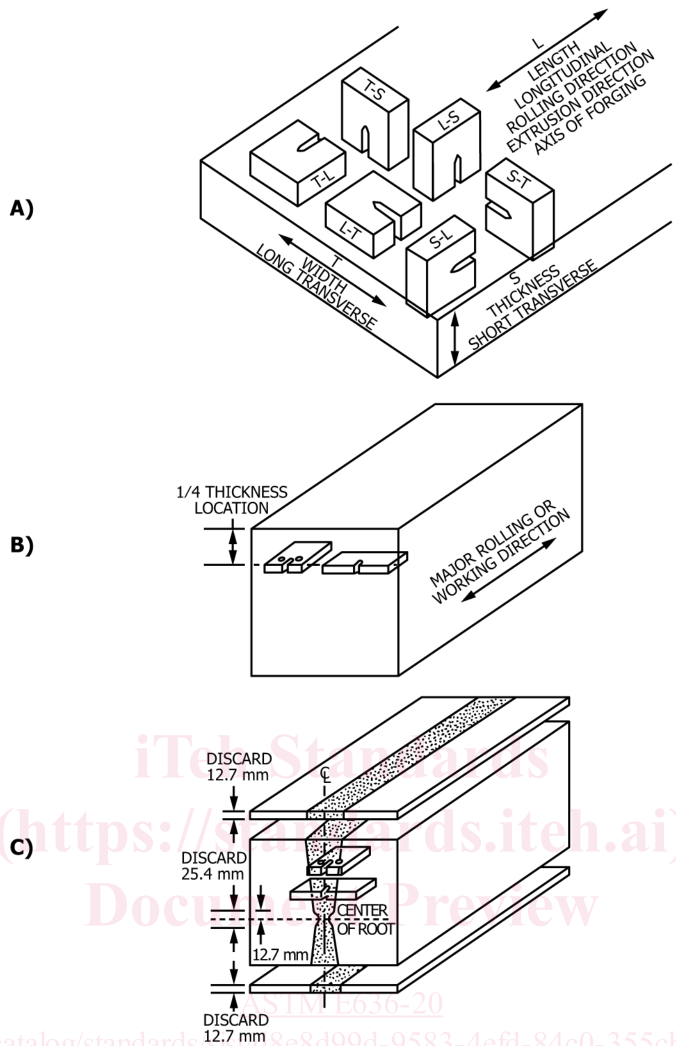

FIG. 1 Specimen Orientation and Location in Plate, Forging, and Weld Deposit Materials: A) Crack Plane Orientation Code; B) Plate and Forging Specimen Location and Orientation; C) Weld Specimen Location and Orientation

5.2.1 *General*—The recommendations of Practice E185 concerning the encapsulation of specimens, temperature and neutron fluence monitoring, and irradiation exposure conditions ~~should~~shall be followed. The ~~larger~~ size of some supplemental test specimens may require additional consideration of temperature gradients and neutron fluence rate gradients within individual specimens and within the specimen capsules.

5.2.2 *Specimen Irradiation*—Supplemental test specimens may be irradiated in the same capsule as the specimens required by Practice E185 when supplemental results are desired.

5.3 *Specimen Handling and Remote Test Equipment:*

5.3.1 *General*—For testing in a controlled area or in a hot cell facility, remote devices for accurately positioning the specimen in the test machine are generally required. For notched or precracked ~~Charpy-sized~~Charpy-type impact specimens, automatic devices to position the specimen on the test anvils are strongly recommended. Additional remote devices for specimen heating and cooling and for the attachment of measuring fixtures are also necessary. Remote testing equipment shall satisfy the tolerances and accuracy requirements of the applicable ASTM standards for the test method(s) employed.

5.4 *Specimen Testing*—It is recommended that post-irradiation Charpy V-notch impact and tensile tests be performed in accordance with Practice E2215 prior to supplemental specimen testing to establish a basis for selecting test temperatures for the supplemental specimens tested under this method.

5.5 *Documentation:*

5.5.1 The report shall include the reporting requirements on material identification and irradiation history required by Practice E185. Emphasis should be placed on the reporting of tensile properties with fracture toughness test ~~results. See~~results (see 6.1.3.2).

5.5.2 Names and models of testing and monitoring equipment, and the accuracy to which they operate, will be reported. Any special modifications (for example, force damping equipment, etc.) to the testing equipment ~~must~~shall be indicated. Pertinent testing procedures used also shall be reported.

5.5.3 ~~To aid in the interpretation of these supplemental surveillance results, data developed in accordance with Practice~~ If applicable, data ~~E2215, including data~~ from reference correlation monitor ~~material~~materials or ~~data from~~ other supplemental surveillance mechanical property ~~tests, should~~tests shall be included in the report or ~~should be referenced suitably.~~referenced suitably to aid in the interpretation of these supplemental surveillance results.

5.5.4 If reconstituted specimens have been used, information concerning the reconstitution technique shall be given in accordance with Guide E1253.

6. Fracture Toughness ~~Test~~Testing

6.1 *Specimen Design and Possible Modifications:*

6.1.1 *Specimen*—The compact, single-edge bend or disk-shaped compact specimen ~~of~~with dimensions outlined in Test Method ~~E399, Test Method~~ E1820, or Test Method E1921, allowing for design modification (see 6.1.2) for surveillance capsules, ~~will~~shall be used for testing.

6.1.2 *Possible Design Modification*—Modified specimens are useful when test stock or irradiation space is limited, or when gamma heating or neutron fluence rate gradients must be minimized. An example of reconstituted ~~Charpy-sized~~Charpy-type specimen is illustrated in Fig. 2. Specimens have also been modified after irradiation to improve their measuring capabilities. For example, many early pressurized water reactors (PWR) contain wedge-opening loaded (WOL) fracture mechanics specimens. These specimens were originally intended for testing in the brittle fracture regime. For ductile materials, bending can occur in the loading arms of these specimens and the tests become invalid. However, techniques have been developed to make these specimens useful for testing under ductile conditions. These include extension of the fatigue precrack or modification of the specimen dimensions, or both (**1**).[4] Modified specimen designs may be employed for irradiation, provided that it is shown in advance that their use will not significantly diminish the accuracy of the test or alter test results; if correlations with standard specimen test results have to be employed, their justification and accuracy shall be provided.

6.1.2.1 The pinhole spacings for compact specimens recommended in Test Method E399 and Test Methods E1820 or E1921 are different. However, this difference does not significantly affect the stress field at the crack tip and, therefore, either pinhole spacing is acceptable for surveillance testing (**2**).

6.1.3 *Fatigue Precracking*—Fatigue precracking shall be performed in accordance with either Test Method ~~E399, Test Method~~ E1820~~,~~ or Test Method E1921, as discussed in 6.1.3.1 – 6.1.3.3.

6.1.3.1 ~~*Elastic and*~~ *Elastic-Plastic Fracture Behavior*—When testing is expected to be performed at temperatures where the specimen ultimately fractures by cleavage, the crack size-to-width ratio, *a/W*, ~~should~~shall range between 0.45 and 0.55, and precracking ~~should~~shall be accomplished in accordance with Test Method ~~E399 or Test Method~~ E1921.

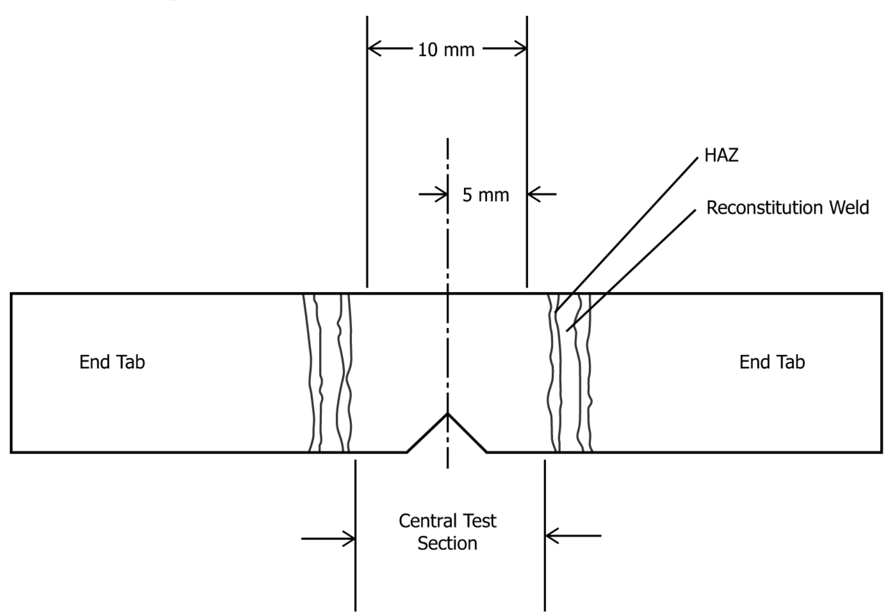

FIG. 2 Example of Reconstituted ~~Charpy-sized~~Charpy-Type Specimen

[4] The boldface numbers in parentheses refer to a list of references at the end of this guide.