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Standard Practice for Evaluation of Surveillance Capsules from Light-Water Moderated Nuclear Power Reactor Vessels[1]

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1. Scope

1.1 This practice covers the evaluation of test specimens and dosimetry from light water moderated nuclear power reactor pressure vessel surveillance capsules.

1.2 This practice is one of a series of standard practices that outline the surveillance program required for nuclear reactor pressure vessels. The surveillance program monitors the radiation-induced changes in the ferritic steels that comprise the beltline of a light-water moderated nuclear reactor pressure vessel.

1.3 This practice along with its companion surveillance program practice, Practice E185, is intended for application in monitoring the properties of beltline materials in any light-water moderated nuclear reactor.[2]

1.4 Modifications to the standard test program and supplemental tests will be described in a separate Standard that is under development to accompany this standard practice and Practice E185.

2. Referenced Documents

2.1 *ASTM Standards:*[3]

A370 Test Methods and Definitions for Mechanical Testing of Steel Products

A751 Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products

E8 Test Methods for Tension Testing of Metallic Materials

E21 Test Methods for Elevated Temperature Tension Tests of Metallic Materials

E23 Test Methods for Notched Bar Impact Testing of Metallic Materials

E170 Terminology Relating to Radiation Measurements and Dosimetry

E185 Practice for Design of Surveillance Programs for Light-Water Moderated Nuclear Power Reactor Vessels

E208 Test Method for Conducting Drop-Weight Test to Determine Nil-Ductility Transition Temperature of Ferritic Steels

E482 Guide for Application of Neutron Transport Methods for Reactor Vessel Surveillance, E706 (IID)

E509 Guide for In-Service Annealing of Light-Water Moderated Nuclear Reactor Vessels

E560 Practice for Extrapolating Reactor Vessel Surveillance Dosimetry Results, E 706(IC)[4]

E636 Guide for Conducting Supplemental Surveillance Tests for Nuclear Power Reactor Vessels, E 706 (IH)

E693 Practice for Characterizing Neutron Exposures in Iron and Low Alloy Steels in Terms of Displacements Per Atom (DPA), E 706(ID)

E706 Master Matrix for Light-Water Reactor Pressure Vessel Surveillance Standards, E 706(0)

E844 Guide for Sensor Set Design and Irradiation for Reactor Surveillance, E 706(IIC)

E853 Practice for Analysis and Interpretation of Light-Water Reactor Surveillance Results, E706(IA)

E900 Guide for Predicting Radiation-Induced Transition Temperature Shift in Reactor Vessel Materials, E706 (IIF)

E1214 Guide for Use of Melt Wire Temperature Monitors for Reactor Vessel Surveillance, E 706 (IIIE)

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

2.2 *Other Documents:*

American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Sections III and XI [5]

ASME Boiler and Pressure Vessel Code Case N-629, Use of Fracture Toughness Test Data to Establish Reference Temperature for Pressure Retaining Materials, Section XI, Division 1[5]

[1] This practice 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.

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[2] Prior to the adoption of these standard practices, surveillance capsule testing requirements were only contained in Practice E185.

[3] 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.

[4] Withdrawn. The last approved version of this historical standard is referenced on www.astm.org.

[5] Available from American Society of Mechanical Engineers, Third Park Avenue, New York, NY 10016.

ASME Boiler and Pressure Vessel Code Case N-631 Use of Fracture Toughness Test Data to Establish Reference Temperature for Pressure Retaining Materials Other Than Bolting for Class 1 Vessels, Section III, Division 1[5]

3. Terminology

3.1 *Definitions:*

3.1.1 *adjusted reference temperature (ART)*—the reference temperature adjusted for irradiation effects by adding to the initial RT_{NDT} , the transition temperature shift, (for example, see Guide E900), and an appropriate margin to account for uncertainties.

3.1.2 *base metal (parent material)*—as-fabricated plate material or forging material other than a weld or its corresponding heat-affected-zone (HAZ).

3.1.3 *beltline*—the irradiated region of the reactor vessel (shell material including weld seams and plates or forgings) that directly surrounds the effective height of the active core, and adjacent regions that are predicted to sustain sufficient neutron damage to warrant consideration in the selection of surveillance material.

3.1.4 *Charpy transition region*—the region on the Charpy transition curve in which toughness increases rapidly with rising temperature; in terms of fracture appearance, it is characterized by a change from a primarily cleavage (crystalline) fracture mode to a primarily shear (fibrous) fracture mode.

3.1.5 *Charpy transition temperature curve* —a graphic presentation of Charpy data, including absorbed energy, lateral expansion, and fracture appearance as functions of test temperature, extending over a range including the lower shelf energy (5 % or less shear fracture appearance), transition region, and the upper-shelf energy (95 % or greater shear fracture appearance).

3.1.6 *Charpy transition temperature shift*—the difference in the 30 ft-lbf (41 J) index temperatures for the best fit (average) Charpy curve measured before and after irradiation.

3.1.7 *Charpy upper shelf energy level*—the average energy value for all Charpy specimen tests (normally three) whose test temperature is above the Charpy upper shelf onset; specimens tested at temperature greater than 150°F (83°C) above the Charpy upper-shelf onset need not be included. The range of test temperatures for which energy values were averaged must be reported as well as the individual energy values. For specimens tested in sets of three at each test temperature, the set having the highest average may be regarded as defining the upper-shelf energy.

3.1.8 *Charpy upper shelf onset*—the test temperature above which the fracture appearance of all Charpy specimens tested is nominally 100 % shear. Specimens with 95 % or greater shear may be included in this determination.

3.1.9 *end-of-life (EOL)*—the design lifetime in terms of years corresponding to the operating license period.

3.1.10 *fracture strength*—in a tensile test, the measured force at fracture divided by the initial cross-sectional area of the test specimen.

3.1.11 *fracture stress*—in a tensile test, the measured force at fracture divided by the cross-sectional area of the test specimen at the time of fracture.

3.1.12 *heat-affected-zone (HAZ)*—plate material or forging material extending outward from, but not including, the weld fusion line in which the microstructure of the base metal has been altered by the heat of the welding process.

3.1.13 *index temperature*—that temperature corresponding to a predetermined level of absorbed energy, lateral expansion, or fracture appearance obtained from the best-fit (average) Charpy transition curve.

3.1.14 *lead factor*—the ratio of the neutron fluence rate ($E > 1$ MeV) at the specimens in a surveillance capsule to the neutron fluence rate ($E > 1$ MeV) at the reactor pressure vessel inside surface peak fluence location.

NOTE 1—Changes in the reactor operating parameters and fuel management may cause the lead factor to change.

3.1.15 *nil-ductility transition temperature* (T_{NDT})—the maximum temperature at which a standard drop weight specimen breaks when tested in accordance with Test Method E208.

3.1.16 *reference material*—any steel that has been characterized as to the sensitivity of its mechanical and fracture toughness properties to neutron radiation embrittlement.

3.1.17 *reference temperature* (RT_{NDT})—see subarticle NB-2300 of the ASME Boiler and Pressure Vessel Code, Section III, "Nuclear Power Plant Components" for the definition of RT_{NDT} for unirradiated material. ASME Code Cases N-629 and N-631 provide an alternative definition for the reference temperature (RT_{To})

3.2 *Neutron Exposure Terminology*:

3.2.1 Definitions of terms related to neutron dosimetry and exposure are provided in Terminology E170.

4. Significance and Use

4.1 Neutron radiation effects are considered in the design of light-water moderated nuclear power reactors. Changes in system operating parameters may be made throughout the service life of the reactor to account for these effects. A surveillance program is used to measure changes in the properties of actual vessel materials due to the irradiation environment. This practice describes the criteria that should be considered in evaluating surveillance program test capsules.

4.2 Prior to the first issue date of this standard, the design of surveillance programs and the testing of surveillance capsules were both covered in a single standard, Practice E185. Between its provisional adoption in 1961 and its replacement linked to this standard, Practice E185 was revised many times (1966, 1970, 1973, 1979, 1982, 1993 and 1998). Therefore, capsules from surveillance programs that were designed and implemented under early versions of the standard were often tested after substantial changes to the standard had been adopted. For clarity, the standard practice for surveillance programs has been divided into the new Practice E185 that covers the design of new surveillance programs and this standard practice that covers the testing and evaluation of surveillance capsules. A future standard is planned which will recommend procedures for modifying and supplementing existing surveillance programs both in terms of design and testing.

4.3 This standard practice is intended to cover testing and evaluation of all light-water moderated reactor pressure vessel surveillance capsules. The practice is applicable to testing of capsules from surveillance programs designed and implemented under all previous versions of Practice E185.

4.4 The radiation-induced changes in the properties of the vessel are generally monitored by measuring the Charpy transition temperature, the Charpy upper shelf energy and the tensile properties of specimens from the surveillance program capsules. The significance of these radiation-induced changes is described in Practice E185. The application of this data is the subject of Guide E900 and other documents listed in Section 2.

4.5 Alternative methods exist for testing surveillance capsule materials. Some supplemental and alternative testing methods are available as indicated in Practice E636. Direct measurement of the fracture toughness is also feasible using the T_o Reference Temperature method defined in Test Method E1921 or J-integral techniques defined in Test Method E1820. Additionally hardness testing can be used to supplement standard methods as a means of monitoring the radiation response of the materials.

4.6 The methodology to be used in the analysis and interpretation of neutron dosimetry data and the determination of neutron fluence is defined in Practice E853.

4.7 Guide E900 describes the bases used to evaluate the radiation-induced changes in Charpy transition temperature for reactor vessel materials and provides a methodology for predicting future values.

5. Determination of Capsule Condition

5.1 *Visual Examination*—A complete visual exam of the capsule condition should be completed upon receipt and during disassembly at the testing laboratory. External identification marks on the capsule shall be verified. Signs of damage or degradation of the capsule exterior shall be recorded.

5.2 *Capsule Content*—The specimen loading pattern should be compared to the capsule fabrication records and any deviations shall be noted. Any evidence of corrosion or other damage to the specimens shall also be noted. The condition of any thermal monitors shall be noted and recorded.

5.3 *Irradiation Temperature History*—The average capsule temperature during full power operation shall be estimated for each reactor fuel cycle prior to capsule removal. The local reactor coolant temperature may be used as a reasonable approximation. In a typical pressurized water reactor, the coolant inlet temperature may be used as an estimate of the capsule irradiation temperature using a time-weighted average (see Guide E900). In a typical boiling water reactor, the recirculation temperature may be used as an estimate of the capsule irradiation temperature.

5.4 *Peak Temperature Monitors*—Thermal monitors shall be examined and any evidence of melting shall be recorded in accordance with Guide E1214.

6. Measurement of Irradiation Exposure

6.1 The power history of the reactor for all cycles prior to capsule removal shall be recorded. Vessel dimensional information and capsule locations shall be provided for the evaluation of irradiation exposure.

6.2 The neutron fluence rate, neutron energy spectrum and neutron fluence of the surveillance specimens and the corresponding maximum values for the reactor vessel shall be determined in accordance with Practices E853 and E560.

6.3 Neutron fluence rate and fluence values ($E > 1 MeV$) and dpa rate and dpa values shall be determined and recorded using a calculated spectrum adjusted or validated by dosimetry measurements.

7. Measurement of Mechanical Properties

7.1 *Tension Tests*:

7.1.1 *Method*—Tension testing shall be conducted in accordance with Test Methods E8 and E21.

7.1.2 *Test Temperature*—In general, the test temperatures for each material shall include room temperature, service temperature, and, if a specimen is available, one intermediate temperature to define the strength versus temperature relationship. Specific consideration should be given to the specific temperatures at which unirradiated specimens have been tested.

7.1.3 *Measurements*—Determine yield strength, tensile strength, fracture strength, fracture stress, total and uniform elongation and reduction of area.

7.2 *Charpy Tests*:

7.2.1 *Method*—Charpy tests shall be conducted in accordance with Test Methods and Definitions A370 and Test Method E23. Instrumented tests are recommended and should be performed in accordance with Practice E636. Broken Charpy specimens may be reconstituted for supplemental testing in accordance with Guide E1253.

7.2.2 *Test Temperature*—Specimens for each material shall be tested at temperatures selected to define the full energy transition curve. Particular emphasis should be placed on defining the 30 ft-lbf (41 J) index temperatures and the upper shelf energy.

7.2.3 *Measurements*—For each test specimen, measure the impact energy, lateral expansion, and percent shear fracture appearance.

7.3 *Hardness Tests (Optional)*—Hardness tests may be performed on irradiated Charpy specimens. The measurements shall be taken in areas away from the fracture zone or the edges of the specimens. The tests shall be conducted in accordance with Test Methods and Definitions A370.

7.4 *Fracture Toughness Tests (Optional)*:

7.4.1 *Specimens*—Supplemental fracture toughness tests may be conducted following Practice E636 using either fracture mechanics specimens from the surveillance capsule or broken Charpy specimens that have been reconstituted. Procedures for reconstitution of Charpy specimens are given in Guide E1253.

7.4.2 *Upper Shelf Fracture Toughness*—Testing to characterize upper shelf toughness using the J-integral method should be conducted in accordance with Test Method E1820.

7.4.3 *Transition Fracture Toughness*—The reference temperature for ferritic steels in the transition range, T_o, can be established using the methodology provided in Test Method E1921.

7.5 *Retention of Broken Test Specimens*—It is recommended that all broken test specimens be maintained in good condition and retained in the event that additional analysis is required to explain anomalous results. Identification of broken