Designation:E 185–94 Designation: E185 – 10

Standard Practice for Conducting Surveillance Tests for Light-Water Cooled Nuclear Power Reactor Vessels, E 706 (IF)Design of Surveillance Programs for Light-Water Moderated Nuclear Power Reactor Vessels[1]

This standard is issued under the fixed designation E185; 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.

1. Scope

1.1This practice covers procedures for monitoring the radiation-induced changes in the mechanical properties of ferritic materials in the beltline of light-water cooled nuclear power reactor vessels. This practice includes guidelines for designing a minimum surveillance program, selecting materials, and evaluating test results.

1.2This practice was developed for all light-water cooled nuclear power reactor vessels for which the predicted maximum neutron fluence (

1.1 This practice covers procedures for designing a surveillance program for monitoring the radiation-induced changes in the mechanical properties of ferritic materials in light-water moderated nuclear power reactor vessels. This practice includes the minimum requirements for the design of a surveillance program, selection of vessel material to be included, and the initial schedule for evaluation of materials.

1.2 This practice was developed for all light-water moderated nuclear power reactor vessels for which the predicted maximum fast neutron fluence (E > 1 MeV) at the end of the design lifetime exceeds 1×10 > 1 MeV) at the end of license (EOL) exceeds 1×10^{21} neutrons/m^2 (1×10^{17} n/cm^2(1×10^{21} n/m^2) at the inside surface of the reactor vessel.

1.3This practice does not provide procedures for monitoring the radiation induced changes in properties beyond the design life, but the procedure described may provide guidance for developing such a surveillance program.

1.3 This practice applies only to the planning and design of surveillance programs for reactor vessels designed and built after the effective date of this practice. Previous versions of Practice E185 apply to earlier reactor vessels.

1.4 This practice does not provide specific procedures for monitoring the radiation induced changes in properties beyond the design life, but the procedure described may provide guidance for developing such a surveillance program.

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

NOTE 1—The increased complexity of the requirements for a light-water moderated nuclear power reactor vessel surveillance program has necessitated the separation of the requirements into three related standards. Practice E185 describes the minimum requirements for a surveillance program. Practice E2215 describes the procedures for testing and evaluation of surveillance capsules removed from a surveillance program as defined in the current or previous editions of Practice E185. Guide E636 provides guidance for conducting additional mechanical tests. A summary of the many major revisions to Practice E185 since its original issuance is contained in Appendix X1.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

A370 Test Methods and Definitions for Mechanical Testing of Steel Products

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

E88/E8M 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

E208170 Terminology Relating to Radiation Measurements and Dosimetry

[1] This practice is under the jurisdiction of ASTM Committee E-10 E10 on Nuclear Technology and Applications and is the direct responsibility of Subcommittee E10.02 on Behavior and Use of Structural Materials.

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[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* , Vol 01.03.volume information, refer to the standard's Document Summary page on the ASTM website.

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, E 706 (IID)~~
~~E509Guide for In-Service Annealing of Light-Water Cooled Nuclear Reactor Vessels~~[4]
Guide for Application of Neutron Transport Methods for Reactor Vessel Surveillance, E706 (IID)
E~~560Practice for Extrapolating Reactor Vessel Surveillance Dosimetry Results, E 706 (IC)~~[4]
~~E636~~636 ~~Practice for Conducting Supplemental Surveillance Tests for Nuclear Power Reactor Vessels, E 706 (IH)~~[4]
~~E706Master Matrix for Light-Water Reactor Pressure Vessel Surveillance Standards, E 706 (O)~~[4]
Guide for Conducting Supplemental Surveillance Tests for Nuclear Power Reactor Vessels, E 706 (IH)
E844 Guide for Sensor Set Design and Irradiation for Reactor Surveillance, E 706 (IIC)
E~~853Practice for Analysis and Interpretation of Light-Water Reactor Surveillance Results, E 706 (IA)~~[4]
~~E900~~900 ~~Guide for Predicting Neutron Radiation Damage to Reactor Vessel Materials, E 706 (IIF)~~[4]
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)~~[4] 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
E2215 Practice for Evaluation of Surveillance Capsules from Light-Water Moderated Nuclear Power Reactor Vessels

2.2 ~~*Other Document:*~~ *ASME Standards:*[3]
American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Sections III and XI
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
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

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, and an appropriate margin.~~ base metal—as-fabricated plate material or forging material other than a weld or its corresponding heat-affected-zone (HAZ).

3.1.2 ~~*base metal (parent material)*—as-fabricated plate material or forging material other than a weldment 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~~core. Note that materials in regions adjacent to ~~experience~~ the beltline may sustain sufficient neutron damage to warrant consideration in the selection of surveillance materials.

~~3.1.4~~3.1.3 *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), transition region, and the upper-shelf energy (95% or greater).~~ —a graphic or curve-fitted presentation, or both, of absorbed energy, lateral expansion, and fracture appearance as functions of test temperature, extending over a range including the lower shelf (5 % or less shear fracture appearance), transition region, and the upper shelf (95 % or greater shear fracture appearance).

3.1.4 *Charpy transition temperature shift*—the difference in the 40.7 J (30 ft-lbf) index temperatures for the best fit (average) Charpy absorbed energy curve measured before and after irradiation.

3.1.5 ~~*correlation monitor*—any steel that has been characterized as to the sensitivity of its mechanical and fracture toughness properties to neutron radiation embrittlement.~~ Charpy upper-shelf energy level—the average energy value for all Charpy specimen tests (preferably three or more) whose test temperature is at or above the Charpy upper-shelf onset; specimens tested at temperatures greater than 83°C (150°F) above the Charpy upper-shelf onset shall not be included, unless no data are available between the onset temperature and onset +83°C (+150°F).

3.1.6 ~~*end-of-life (EOL)*—the design lifetime in terms of years, effective full power years, or neutron fluence.~~ Charpy upper-shelf onset—the test temperature above which the fracture appearance of all Charpy specimens tested is at or above 95 % shear.

3.1.7 ~~*fracture strength—in a tensile test*, the load at fracture divided by the initial cross-sectional area of the test specimen.~~ end-of-license (EOL)—the design lifetime in terms of years corresponding to the operating license period.

3.1.8 ~~*fracture stress—in a tensile test*, the load at fracture divided by the cross-sectional area of the test specimen at time of fracture.~~ 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] Annual Book of ASTM Standards, Vol 03.01.~~
[3] Available from the American Society of Mechanical Engineers, Third Park Avenue, New York, NY 10016.

3.1.9 *heat-affected zone (HAZ)*—plate material or forging material in which the microstructure of the base metal has been altered by the heat of the welding process, and which extends outward from, but does not include any of, the weld fusion zone.

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

3.1.113.1.10 *lead factor*—the ratio of the peak neutron fluence rate

($E > 1$ MeV) of the specimens in a surveillance capsule to the peak neutron fluence rate ($E > 1$ MeV) at the reactor pressure vessel inside surface peak fluence. > 1 MeV) at the reactor pressure vessel inside surface.

3.1.10.1 *Discussion*—Changes in the reactor operating parameters and fuel management may cause the lead factor to change.

3.1.11 *limiting materials*—the weld and base material with the highest predicted transition temperature at EOL determined by adding the appropriate transition temperature shift to the unirradiated RT_{NDT}. The reference temperature shift can be determined from the relationship found in Guide E900. The basis for selecting the limiting material shall be documented.

3.1.12 *margin*—an addition included in the adjusted reference temperature to account for uncertainties in the data. reference material—any steel that has been characterized as to the sensitivity of its tensile, impact and fracture toughness properties to neutron radiation embrittlement.

3.1.13 *nil-ductility transition temperature (T_{NDT}*reference temperature (RT_{NDT}) —the maximum temperature at which a standard drop weight specimen breaks when tested in accordance with Test Method E 208E 208.

3.1.14*onset of upper-shelf*—the test temperature above which the fracture appearance of all Charpy specimens tested is nominally 100% shear. Specimens with 5% or less cleavage may be included in this determination.

3.1.15*reference temperature (RT*—see subarticle NB-2300 of the ASME Boiler and Pressure Vessel Code, Section III, "Nuclear Power Plant Components" for the definition of 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.

3.1.16*transition region*—the region on the Charpy transition temperature 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 primarily shear (fibrous) fracture mode.

3.1.17*transition temperature shift* (ΔRT_{NDT})—the difference in the 30 ft·lbf (40.7 J) index temperatures for the best fit (average) Charpy curve measured before and after irradiation.

3.1.18*upper-shelf energy level*—the average energy value for all Charpy specimen tests (normally three) whose test temperature is above the onset of upper-shelf behavior; specimens tested at temperature greater than 150°F (83°C) above the onset of upper-shelf need not be included.

3.1.18.1*Discussion*—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.

3.2*Definitions of Terms Specific to This Standard:*

3.2.1The following definitions are intended for application to this standard and may not be in agreement with definitions of the same parameters given in other standards:

3.2.1.1*neutron fluence*— the time integrated neutron fluence rate, expressed in neutrons per square meter or neutrons per square centimeter.

3.2.1.2*neutron fluence rate*—a measure of the intensity of neutron radiation within a given range of neutron energies; the product of the neutron density and velocity, expressed in neutrons per square meter-second or neutrons per square centimeter-second.

3.2.1.3*neutron spectrum*— the distribution by energy levels of neutrons impinging on a surface, as determined from analysis of multiple neutron dosimeter measurements or from a calculation of the neutron energy distribution. for unirradiated material based on Charpy (Test Method E23) and drop weight tests (Test Method E208). ASME Code Cases N-629 and N-631 provide an alternative definition for the reference temperature (RT_{To}) based on fracture toughness properties (Test Method E1921)

3.1.14 *standby capsule*—a surveillance capsule meeting the recommendations of this practice that is in the reactor vessel irradiation location, but whose withdrawal is not required by this practice.

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 Predictions of neutron radiation effects on pressure vessel steels are considered in the design of light-water cooledmoderated nuclear power reactors. Changes in system operating parameters often are made throughout the service life of the reactor vessel to account for radiation effects. Because ofDue to the variability in the behavior of reactor vessel steels, a surveillance program is warranted to monitor changes in the properties of actual vessel materials caused by long-term exposure to the neutron radiation and temperature environment of the given reactor vessel. This practice describes the criteria that should be considered in planning and implementing surveillance test programs and points out precautions that should be taken to ensure that: (*1*) capsule exposures can be related to beltline exposures, (*2*) materials selected for the surveillance program are samples of those materials most likely to limit the operation of the reactor vessel, and (*3*) the tests yield results useful for the evaluation of radiation effects on the reactor vessel.

4.2The methodology to be used in the analysis and interpretation of neutron exposure data obtained from reactor vessel surveillance programs as defined in Practice E 853E 853 establishes the bases to be used to evaluate both the present and future conditions of the reactor vessel.

4.3The design of a surveillance program for a given reactor vessel must consider the existing body of data on similar materials in addition to the specific materials used for that reactor vessel. The amount of such data and the similarity of exposure conditions and material characteristics will determine their applicability for predicting the radiation effects. As a large amount of pertinent data becomes available, it may be possible to reduce the surveillance effort for selected reactors by integrating their surveillance programs.

5.Test Materials

5.1*Materials Selection*:

5.1.1Surveillance test materials shall be full thickness samples taken from the actual materials used in fabricating the beltline of the reactor vessel. These surveillance test materials shall include a minimum of one heat of the base metal and one butt weld. The base metal and weld metal materials included in the program shall be those predicted to be most limiting with regard to setting pressure-temperature limits for operation of the reactor to compensate for radiation effects during its lifetime. The beltline materials shall be evaluated on the basis of adjusted reference temperature. The predicted changes in the initial properties as a function of chemical composition and the neutron fluence during reactor operation shall be determined in accordance with Guide E 900E 900. The base metal and the weld with the highest adjusted reference temperature at end-of-life shall be selected for the surveillance program. If the Charpy upper-shelf energy of any of the beltline materials is predicted to drop to a marginal level (currently considered to be 50 ft·lb (67.8 J) at the quarter thickness (¼ *T*) location) during the operating lifetime of the vessel, provisions shall be made to also include that material in the surveillance program. It is recommended that the selected material be in the form of fracture toughness specimens (Practice E 636E 636).

5.1.2The adjusted reference temperature of each material in the reactor vessel beltline shall be determined by adding the value of transition temperature shift to the reference temperature of the unirradiated material plus an appropriate margin. The reference temperature shift and Charpy upper-shelf energy drop can be determined from relationships of fluence and chemical composition. A procedure for making this determination is described in Guide E 900E 900) the test specimen types are appropriate for the evaluation of radiation effects on the reactor vessel.

4.2 The methodology to be used in estimation of neutron exposure obtained for reactor vessel surveillance programs is defined in Guide E482.

4.3 The design of a surveillance program for a given reactor vessel must consider the existing body of data on similar materials in addition to the specific materials used for that reactor vessel. The amount of such data and the similarity of exposure conditions and material characteristics will determine their applicability for predicting radiation effects.

5. Surveillance Program Design

5.1 This section describes the minimum requirements for the design of a surveillance program for monitoring the radiation-induced changes in the mechanical properties of ferritic materials in the reactor vessel.

5.2 *Test Materials*:

5.2.1 *Materials Selection*—The surveillance test materials shall include, at minimum, the limiting base metal heat and the limiting weld. If a limiting material is outside the beltline, the limiting beltline base and weld materials shall also be included.

NOTE 2—The predicted limiting material may change during operation. Therefore, it is prudent to include additional potentially limiting beltline materials in the surveillance program as capsule space permits.

5.2.2 *Material Sampling*—A minimum test program shall consist of the material selected in 5.2.1, taken from the following locations:following: (*1*) base metal from one plate or forging used in the beltline, and (*) base metal from the actual plate(s) or forging(s) used in the reactor vessel, and (2) weld metal(s) made with the same heat of weld wire and lot of flux and by the same welding procedure as that used for the selected beltline weld.reactor vessel welds. The base metal used to fabricate the weldment(s) shall be one of the base metals included in the surveillance program. Surveillance test materials shall be full thickness samples.*

NOTE1—Experience has shown that it is no longer necessary to include the weld heat-affected zone material in the surveillance program. However, it is recommended that the heat-affected-zone material be included with the archives (see 5.3) and that the material qualification test results be evaluated for anomalous or unusual results, for example, from new or unique fabrication procedures that may yield degraded heat-affected-zone properties.

5.3*Archive Materials*—Sufficient test stock to fill at least two additional capsules with test specimens of the base metal and weld materials used in the program shall be retained with full documentation and identification. This test stock should be in the form of full-thickness sections of the original materials (plates, forgings, and welds). It is recommended that the designated heat-affected-zone materials be retained to provide supplemental data.

5.4 *3—Experience has shown that it is no longer necessary to include the heat-affected zone material in the surveillance program. However, it is recommended that the heat-affected-zone material be included with the archives (see 5.2.5).*

5.2.3 *Fabrication History*—The fabrication history (austenitizing, quench and tempering, and post-weld heat treatment) of the test materials shall be fully representative of the fabrication history of the materials in the beltline of the reactor vessel reactor vessel materials selected in 5.2.1 and shall be recorded.

5.55.2.4 *Chemical Analysis Requirements*—The chemical analysis required by the appropriate product specifications for the

~~surveillance test materials (base metal and as-deposited weld metal) shall be recorded and shall include phosphorus (P), sulfur (S), copper (Cu), vanadium (V), and nickel (Ni), as well as all other alloying and residual elements commonly analyzed for in low-alloy steel products. The product analysis shall be as described in Test Methods, Practices and Terminology A 751A 751 and verified by analyzing a minimum of three samples randomly selected from both the base metal and the as-deposited weld metal.~~

~~6.Test Specimens~~

~~6.1~~—*The chemical analysis required by the appropriate product specifications for the surveillance test materials (base metal and as-deposited weld metal) shall be recorded and shall include phosphorus (P), sulfur (S), copper (Cu), vanadium (V), silicon (Si), manganese (Mn), and nickel (Ni), as well as all other alloying and residual elements commonly analyzed for in low-alloy steel products. The product analysis shall be as described in Test Method A751 and verified by analyzing samples selected from the base metal and the as-deposited weld metal.*

5.2.5 *Archive Materials*—Test stock to fill up to six additional capsules beyond the minimum number required for testing with test specimens of the base metal and weld materials used in the program shall be retained with full documentation and identification. This stock should be in the form of full-thickness sections of the original materials (plates, forgings, and welds) except specimens included in standby capsules. It is recommended that the heat-affected-zone material associated with the archive weld material be retained to provide supplemental data.

5.3 *Test Specimens*

5.3.1 *Type of Specimens*~~—Charpy V-notch specimens corresponding to the Type A specimen described in Test Methods A 370 and E 23A 370E 23 shall be used. The gage section of irradiated and unirradiated tension specimens shall be of the same size and shape. Tension specimens of the type, size, and shape described in Test Methods A 370 and E 8A 370E 8 are recommended. Additional fracture toughness test specimens shall be employed to supplement the information from the Charpy V-notch specimens if the surveillance materials are predicted to exhibit marginal properties (see Practice E 636E 636).~~

~~6.2~~—*Charpy V-notch specimens corresponding to the Type A specimen described in Test Methods A370 and E23 shall be used. Tension specimens of the type, size, and shape described in Test Methods A370 and E8/E8M are recommended. The gage section of irradiated and unirradiated tension specimens shall be of the same size and shape. Fracture toughness test specimens shall be consistent with the guidelines provided in Test Methods E1820 and E1921.*

5.3.2 *Specimen Orientation and Location*—Tension, Charpy and ~~Charpy~~ fracture toughness specimens representing the base metal shall be removed from about the quarter-thickness (¼ ~~T)~~ -T or ¾-T) locations. Material from the mid- thickness of the ~~plates~~ base metal shall not be used for test specimens. Specimens representing weld metal may be removed from any location throughout the thickness with the exception of locations within 12.7 mm (½ in.) of the root or surfaces of the welds. Special attention must be given to defining the root of the weld in order to avoid taking weld metal that is different in composition from the surveillance weld metal. The tension and Charpy specimens from base metal shall be oriented so that the major axis of the specimen is parallel to the surface and normal to the principal rolling direction for plates, or normal to the major working direction for forgings ~~as described~~ shown in ~~Section III of the ASME Code.~~Test Method E23, Annex A5 (T-L orientation). The axis of the notch of the Charpy specimen for base metal and weld metal shall be oriented perpendicular to the surface of the material. The recommended orientation of the weld metal specimens is shown in Fig. 1~~. Weld metal tension specimens may be oriented in the same direction as the Charpy specimens provided that the gage length consists entirely of weld metal.~~

~~6.3*Quantities of Specimens*:~~

~~6.3.1~~. *Weld metal tension specimens may be oriented in the same direction as the Charpy specimens provided that the gage length consists entirely of weld metal. The fracture toughness specimens shall have the same orientation as the Charpy specimens in both the base metal and weld metal.*

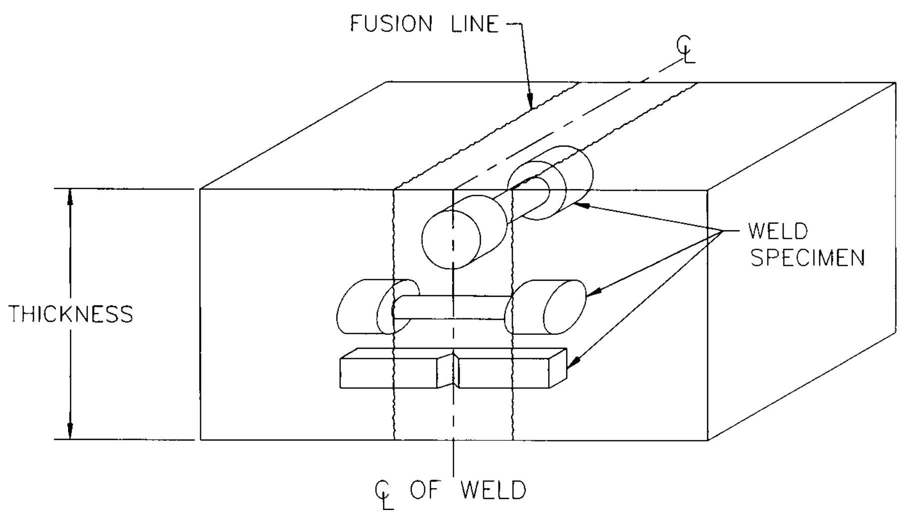

FIG. 1 Location of Test Specimens Within Weld ~~Test~~ Material

5.4 *Number of Specimens*

5.4.1 *Unirradiated Baseline Specimens*~~—It is recommended that 18 Charpy specimens be provided, of which a minimum of 15 specimens shall be tested to establish a full transition temperature and upper-shelf curve for each material (base metal, weld metal, and correlation monitor material). The three remaining Charpy specimens should be reserved to provide supplemental data for conditions such as excessive data scatter. It is recommended that at least six tension test specimens shall be provided to establish the unirradiated tensile properties for both the base metal and the weld metal. A minimum of two specimens should be tested at room temperature and at reactor vessel beltline operating temperature. The remainder of the specimens may be tested at intermediate temperatures as needed to define the effects of temperature on the tensile properties.~~

~~6.3.2~~*—A minimum of 15 Charpy specimens shall be tested to establish full Charpy transition temperature curves for each material per Test Method E23. Instrumented tests are recommended and should be performed in accordance with Guide E636. It is recommended that upper-shelf Charpy tests be conducted at multiple temperatures using at least three specimens tested below the irradiation temperature and above the upper-shelf onset. At least six tension test specimens shall be tested to establish the unirradiated tensile properties for both the base metal and the weld metal. A minimum of two specimens at room temperature (per Test Method E8/E8M) and two specimens at reactor vessel beltline operating temperature (per Test Method E21) should be tested. The remainder of the tensile specimens may be tested at intermediate temperatures as needed to define the effects of temperature on the tensile properties. It is recommended that a minimum of 8 fracture toughness specimens be tested to establish the reference temperature, T_o, per Test Method E1921 for the limiting material. Optionally, fracture toughness tests can be performed to establish the upper-shelf toughness following Test Method E1820.*

5.4.2 *Irradiated Specimens*—The minimum number of test specimens for each irradiation exposure set (capsule) shall be as follows:

Material	Charpy	Tension~~Base Metal~~	Fracture Toughness	
~~Each Base Metal~~	~~12~~	~~3Weld Metal~~	~~128~~[A]	
Each Base Metal	15	3	8[A]	
~~Each Weld Metal~~	~~15~~	~~3Correlation Monitor~~	~~12~~	~~0~~
Each Weld Metal	15	3	~~12~~	~~0~~8[A]

~~It is suggested that a greater quantity of the above specimens be included in the irradiation capsules whenever possible.~~

~~**7.Irradiation Requirements**~~

~~7.1~~

[A] Only fracture toughness specimens from the limiting material are required. It is suggested that a greater quantity of specimens be included in the irradiation capsules whenever possible.

5.5 *Irradiation Requirements*:

5.5.1 *Encapsulation of Specimens*—Specimens should be maintained in an inert environment within a corrosion-resistant capsule to prevent deterioration of the surface of the specimens during radiation exposure. Care should be exercised in the design of the capsule to ensure that the temperature history of the specimens ~~duplicates,~~matches, as closely as possible, the temperature experienced by the reactor vessel. Surveillance capsules ~~should~~shall be ~~sufficiently rigid~~designed to prevent mechanical damage to the specimens and monitors during irradiation. The design of the capsule and capsule attachments shall also permit insertion of replacement capsules into the reactor vessel if required at a later time in the lifetime of the vessel. The design of the capsule holder and the means of attachment shall (*1*) preclude structural material degradation ~~by~~at the ~~attachment welds,~~attachment, (*2*) avoid interference with in-service inspection required by ASME Code Section ~~XI,~~XI, and (*3*) ensure the integrity of the capsule holder during the service life of the reactor vessel.

~~7.2~~

5.5.2 *Location of Capsules*:

~~7.2.1*Vessel Wall Capsules (Required)* —Surveillance capsules shall be located within the reactor vessel so that the specimen irradiation history duplicates as closely as possible, within the physical constraints of the system, the neutron spectrum, temperature history, and maximum neutron fluence experienced by the reactor vessel. It is recommended that the surveillance capsule lead factors be no greater than five. The lead factors shall be selected to reduce the calculational uncertainties in extrapolating the surveillance measurements from the specimens to the reactor vessel wall and maximize the ability of the program to monitor material property changes throughout the life of the reactor vessel. The design of the internals of some reactor vessels may not allow the positioning of surveillance capsules in low fluence locations. Plants with lead factors greater than five should provide for a method of verifying the validity of the data. This may be accomplished by the inclusion of one of the correlation monitor materials (see 7.4) or a similarly characterized material. It should be recognized that during the service life of the reactor vessel the lead factors for individual capsules may change as a result of changes in fuel management.~~

~~7.2.2~~

5.5.2.1 *Vessel Capsules (Required)*—Surveillance capsules shall be located within the reactor vessel so that the specimen irradiation history duplicates as closely as possible, within the physical constraints of the system, the neutron spectrum, temperature history, and maximum neutron fluence experienced by the reactor vessel. The surveillance lead factor should be greater than 1.5 and less than five. A lead factor near 1.5 will provide data that will closely duplicate the fluence of the vessel material and will enable monitoring through most of the operating lifetime. Capsules with higher lead factors will provide data earlier in