Designation: E531 – 23

Standard Practice for Surveillance Testing of High-Temperature Nuclear Component Materials[1]

This standard is issued under the fixed designation E531; 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

1.1 This practice covers procedures for surveillance program design and specimen testing to establish changes occurring in the mechanical properties of ferrous and nickel-based materials due to irradiation and thermal effects of nuclear component metallic materials used for high-temperature structural applications above 370 °C (700 °F). This should include consideration of gamma heating. This practice currently only applies to an initial program based on initial estimates of design life of components.

1.2 This practice was developed for non-light-water moderated nuclear power reactors.

1.3 This practice does not provide specific procedures for extending surveillance programs beyond their original design lifetimes.

1.4 This practice does not consider in-situ monitoring techniques but may provide insights into the proper periodicity and design of such.

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

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.7 *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]

A370 Test Methods and Definitions for Mechanical Testing of Steel Products
E8/E8M Test Methods for Tension Testing of Metallic Materials
E21 Test Methods for Elevated Temperature Tension Tests of Metallic Materials
E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
E45 Test Methods for Determining the Inclusion Content of Steel
E112 Test Methods for Determining Average Grain Size
E139 Test Methods for Conducting Creep, Creep-Rupture, and Stress-Rupture Tests of Metallic Materials
E185 Practice for Design of Surveillance Programs for Light-Water Moderated Nuclear Power Reactor Vessels
E261 Practice for Determining Neutron Fluence, Fluence Rate, and Spectra by Radioactivation Techniques
E482 Guide for Application of Neutron Transport Methods for Reactor Vessel Surveillance
E844 Guide for Sensor Set Design and Irradiation for Reactor Surveillance
E1820 Test Method for Measurement of Fracture Toughness
E2006 Guide for Benchmark Testing of Light Water Reactor Calculations
E2586 Practice for Calculating and Using Basic Statistics
E2714 Test Method for Creep-Fatigue Testing
E2760 Test Method for Creep-Fatigue Crack Growth Testing

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *capsule*—a set of specimens to be placed into the system and extracted at the same time.

3.1.2 *critical component*—critical components are those that are required for the safe operation of the subject design (that is, important to safety). In the context of this practice, it is assumed that these components are structural.

[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] 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.

3.1.3 *representative*—a characteristic that is as close as achievable to the actual properties exhibited or experienced by a material of interest.

3.1.4 *test specimen*—a coupon or a piece of metal cut from a larger metallic piece which is machined to final size for testing to determine physical or mechanical properties.

4. Significance and Use

4.1 The practice contained herein can be used as a basis for establishing conditions for the safe operation of critical structural components. The practices provide for general plant assessment and verification that materials continue meet design criteria and may in addition be of use for asset protection or life extension. The test specimens and procedures presented in this practice are for guidance when establishing a surveillance program.

4.2 This practice for high-temperature materials surveillance programs is used when nuclear reactor component materials are monitored by specimen testing. Periodic testing is performed through the service life of the components to assess changes in selected material properties that are caused by neutron irradiation, thermal effects, chemical reactions, and mechanical stress. The properties of interest are those used as design criteria for the respective nuclear components or well correlated to said criteria (see 5.1.6). The need for surveillance arises from the need to assess predictions of aging material performance to ensure adequate component performance.

4.3 This practice describes specimens and procedures required for the surveillance of multiple components. A surveillance program for a particular component will not necessarily require all test types described herein.

5. Test Specimens

5.1 *Pre-Exposure Material Characterization*—It is important that test specimen materials be characterized prior to exposure and that the following shall be documented as a minimum:

5.1.1 Process history including the percentage of cold work; material designation; manufacturer; heat number; weld and fabrication procedures used; and heat treatment(s).

5.1.2 Original location and orientation in the parent material.

5.1.3 Specimen weight and dimensions.

5.1.4 Chemical analysis results (including the specified elements and appropriate impurity elements). Note that surface and bulk chemistries may vary due to certain processing techniques and should be accounted for.

5.1.5 Specimen origin. All specimens shall be taken from the locations and orientations specified in Test Methods and Definitions A370 and Test Methods E8/E8M. This includes base metal and weld metal to provide a leading indication of material performance for normal operating and accident conditions. Consideration should be given to the utility and practicality of including heat-affected zone (HAZ) material as well.

5.1.6 Mechanical properties required for maintaining assurance of component integrity as part of the surveillance program shall be identified and characterized. Properties may include, but are not restricted to: yield strength, ultimate tensile strength, stress-to-rupture, elongation-to-failure, reduction in area, creep strength, stress rupture life, creep resistance to creep-fatigue, linear elastic fracture toughness, plastic-elastic fracture toughness, and creep crack growth rate. Relevant temperatures of testing shall be identified as necessary to support component integrity. Program shall include specimens matching properties essential to confirming pertinent design life calculations; a minimum of one type of specimen must be selected. Users shall document their justification for specimen type selection and provide this documentation with the initial report.

5.1.7 Mechanical testing of time-independent properties identified in 5.1.6 shall be conducted to provide a pre-exposure baseline for the surveillance program. The number of samples used to determine the time-independent baseline properties should be greater than or equal to the number of specimens following withdrawal of the surveillance capsule. These control tests are recommended to be performed simultaneously with the first set of tests of exposed specimens to ensure that deviations in test results can be attributed to the exposed specimen's environment and not to variations in testing methods. If nonstandard specimens are being used, tests should be conducted during the design phase to ensure expected results are obtained.

5.1.8 The information described in 5.1.1 – 5.1.7 should be reported in a single document.

5.2 *Post-Exposure Material Characterization*—After exposure:

5.2.1 Mechanical properties identified in 5.1.6 shall be measured.

5.2.2 The following shall be reported:

5.2.2.1 Observations from visual examination.

5.2.2.2 Changes in specimen weight and dimensions.

5.2.2.3 Metallographic characteristics (for example, grain size, microstructure, inclusion content, depth of corrosion, and cracking). Test Methods E45 and E112 should be used, as applicable.

5.2.2.4 Quantitative examination of surface chemistry to evaluate leaching, de-alloying, and other changes to the base metal chemistry.

5.2.3 Exposed test specimens should be cleaned in accordance with accepted cleaning procedures. (Refer to ASTM Committee G01 for practices for preparing, cleaning, and evaluating test specimens.) Special consideration should be given to specimens exposed to corrosive coolants to minimize additional corrosion of the specimens once they are removed.

5.3 *Specimen Preparation*—Test specimens shall be standard recommended specimens where possible as described in Test Methods E8/E8M, E21, and E139.

5.3.1 *Size*—In general, when space limitations exist, smaller sized samples and larger quantities of test specimens are recommended. Where it is not possible to use specimens of the recommended size, the least deviation possible from recommended sizes should be adhered to. Nonstandard specimens shall be evaluated by the appropriate regulatory authority prior to use as surveillance specimens to ensure that test results from the use of nonstandard specimens can be correlated with test results from specimens of recommended size. In the event that nonstandard specimens are used for surveillance specimens, the archive, base line, and any thermal control specimens shall be identical to the surveillance specimens. Archive material may be maintained unmachined until testing.

5.3.2 *Surface Condition*—Specimens for tests in which surface condition is critical to the test results should not be finish machined in such critical areas (for example, compact tension sample notches, creep-fatigue specimen test area, surface of density change sample) until just prior to test. Specimens should be oversized to allow for removal of at least 0.1 mm (0.004 in.) of surface prior to test. If significant corrosion is expected during operation, specimens should be oversized on the basis of pre-existing test data, with conservative margin. With the exception of swelling specimens, where possible, test specimens shall be situated/encapsulated in an environment as similar as achievable to the operating environment of their associated components.

5.3.3 *Number of Specimens*—The number of specimens employed to monitor components of similar composition, processing, and exposure conditions shall be sufficient to evaluate the quantitative changes to the mechanical and chemical properties described in 5.2 with a high degree of confidence. Statistical assessment of specimen plans shall be conducted prior to implementation to ensure statistically significant results or control related uncertainty to ensure results will be reliable enough to confirm necessary information. The statistical methodologies described in Practice E2586 are recommended for establishing statistical properties of the test results. The number of required tests may be reduced for subsequent and equivalent reactors based on statistical analysis. Equivalency should be determined by the governing regulatory authority. It is recommended that a sufficient amount of material for two further capsules be retained for archive purposes. Archive material shall be retained in an atmosphere that would not affect the material characteristics of interest. Archive material need not be machined or otherwise finished. Reduction in specimen quantities may be justified by use of large design margins; any such justification shall be documented with surveillance program design and results.

5.3.4 *Material*—Test specimens shall be taken from the material used in component fabrication. The influence of microsegregation on the range of compositions seen in the component and test specimens shall be considered when choosing the locations from which the test specimens are taken to avoid bias between test specimens and component, between different types of specimens, and between different capsules. The material shall be processed at the same time as the component or processed in a fashion identical to the component investigated. Weld and HAZ test specimens shall be taken from excess portions of the components or material from the same heats of the components and weld filler material utilizing the same heat treatments, welding procedures, welding parameters, and welders/operators. Weldments in the test specimens shall be as close as practicable to the design of the component weldment. Surveillance specimens should be selected from those materials known to be most sensitive to operating conditions within the plant and should include, but not necessarily be limited to, materials in the regions of highest neutron fluence rate, temperature, and mechanical stress.

5.4 *Tension Test Specimens*—The type and size of specimen to be used should conform to Test Methods E8/E8M and E21. The location and orientation of test specimens shall be as defined in Test Methods E8/E8M or Test Methods and Definitions A370, or in Practice E185. Both base metal and weld metal specimens shall be taken. For each material state, a minimum set of five specimens shall be included in each capsule to be inserted (that is, five for a base metal, five for an HAZ, and five for a weld metal). Tests shall be conducted at the operating temperature of the component of interest. If safety criteria require that the degradation of tensile properties of the component be known at other temperatures, then additional specimens shall be included for this purpose; for example, if the component is ferritic steel, an additional set of five specimens shall be tested at shutdown temperatures or room temperature to demonstrate adequate ductility during a reactor outage/shutdown.

5.5 *Creep and Stress Rupture in Specimens*—The type and sizes of specimen to be used should conform to the specimens recommended in Test Method E139 to the extent practical but shall accommodate passive in-situ testing. Tests shall be conducted at the operating temperature of the component of interest. For each material state, a minimum set of five specimens shall be included in each capsule to be placed (that is, five for a base metal, five for an HAZ, and five for a weld metal).

5.6 *Creep Fatigue Specimens*—The type and sizes of specimen to be used should conform to the specimens recommended in Test Method E2714 to the extent practical but shall accommodate passive in-situ testing. Tests shall be conducted at the operating temperature of the component of interest. Note that consideration should be given to potential thermal stratification in relevant components. For each material state, a minimum set of five specimens shall be included in each capsule to be placed (that is, five for a base metal, five for an HAZ, and five for a weld metal).

5.7 *Creep Fatigue Crack Growth Specimens*—The type and the sizes of specimen to be used should conform to the specimens recommended in Test Method E2760. The location and orientation of the specimens shall be as defined in Test Methods and Definitions A370. A set of specimens shall be made up of ten of each base metal, HAZ, and weld metal for each capsule. Users may justify that one material is limiting and reduce the quantity necessary of other materials to five specimens of each per capsule. Material representative of the most susceptible region of the HAZ to degradation shall be selected. Testing shall be conducted at a temperature which provides crack growth rates representative of conditions of interest.

5.8 *Fracture Toughness Specimens*—The specimens should conform to the specimens recommended in Test Method E1820. The location and orientation of the specimens shall be as defined in Test Methods and Definitions A370. A set of specimens shall be made up of five of each base metal, HAZ (if