INTERNATIONAL

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Standard Guide for Monitoring the Neutron Exposure of LWR Reactor Pressure Vessels[1]

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INTRODUCTION

Light Water Reactor (LWR) power plant safety analysis reports and subsequent neutron exposure parameter calculations for the reactor pressure vessel (RPV) wall and critical welds need to be verified using modern codes and information from surveillance dosimetry. The location of critical welds relative to the axial and azimuthal fluence rate map should be taken into account, as well as changes in fuel loading during periods when surveillance capsules are exposed and beyond to the end of the reactor's operating license. For many reactors today this interval is 60 years. In the nuclear industry, there is active consideration and evaluation of operating intervals of 80 years. Most reactor surveillance programs were designed based on the guidance of Practice E185 with an operating life of 40 years. The Practice E185 surveillance programs are designed to select and irradiate the RPV material test specimens. The dosimetry in the surveillance capsule is there primarily to measure the neutron fluence to which the capsule's material specimens have been exposed.

In addition, those programs were based on the operating assumptions in place at the time; typically annual out-in core loading patterns and base load operation at a fixed reactor power level. Reactor operations have evolved so that low-leakage core loading patterns (L^3P) are the norm as are 18 month and 24 month fuel cycles and reactor power up-ratings of up to 20 %. Many reactors have now installed flux suppression features such as natural uranium fuel rods, full or part-length hafnium or B_4C rods, or stainless steel rods to minimize the neutron exposure of critical areas of the RPV. Such developments increase the need to comprehensively monitor the RPV accrued fluence through the extended operation period.

This guide is intended to be used together with other Standards to provide best estimates of the neutron exposure and exposure rate (together with uncertainties) at positions at the inner diameter and within the pressure vessel wall of a light water reactor. Also provided will be estimates of gamma-ray exposure and exposure rates to interpret dosimetry sensor photo-reaction and other gamma-ray induced effects. Information used to make these estimates is obtained from coupled neutron-gamma ray transport calculations and from neutron and gamma-ray sensors located in surveillance positions on the core side of the vessel and in the reactor cavity outside the vessel wall (**1**).[2] Benchmark field irradiations of similar monitors also provide valuable information used in the verification of the accuracy of the calculations (**1**).

Knowledge of the time-dependent relationship between exposure parameters at surveillance locations and selected (r, θ, z) locations within the pressure vessel wall is required to allow determination of the time-dependent radiation damage to the RPV. The time dependency must be known to allow proper accounting for complications due to burn-up, as well as changes in core loading configurations (**2-5**). An estimate of the uncertainty in the neutron exposure parameter values at selected (r, θ, z) points in the vessel wall (**1**) is also needed to place an upper bound on the allowable operating lifetime of the reactor vessel without remedial action (**6-9**). (See Guide E509.)

1. Scope

1.1 This guide establishes the means and frequency of monitoring the neutron exposure of the LWR reactor pressure vessel throughout its operating life.

1.2 The physics-dosimetry relationships determined from this guide may be used to estimate reactor pressure vessel damage through the application of Practice E693 and Guide E900, using fast neutron fluence (E > 1.0 MeV and E > 0.1 MeV), displacements per atom (dpa), or damage-function-correlated exposure parameters as independent exposure variables. Supporting the application of these standards are the E853, E944, E1005, and E1018 standards, identified in 2.1.

1.3 *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.*

1.4 *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:*[3]

E170 Terminology Relating to Radiation Measurements and Dosimetry

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

E482 Guide for Application of Neutron Transport Methods for Reactor Vessel Surveillance

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

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

E844 Guide for Sensor Set Design and Irradiation for Reactor Surveillance

E853 Practice for Analysis and Interpretation of Light-Water Reactor Surveillance Neutron Exposure Results

E900 Guide for Predicting Radiation-Induced Transition Temperature Shift in Reactor Vessel Materials

E944 Guide for Application of Neutron Spectrum Adjustment Methods in Reactor Surveillance

E1005 Test Method for Application and Analysis of Radiometric Monitors for Reactor Vessel Surveillance

E1018 Guide for Application of ASTM Evaluated Cross Section Data File

E2005 Guide for Benchmark Testing of Reactor Dosimetry in Standard and Reference Neutron Fields

E2006 Guide for Benchmark Testing of Light Water Reactor Calculations

E2215 Practice for Evaluation of Surveillance Capsules from Light-Water Moderated Nuclear Power Reactor Vessels

2.2 *American Society of Mechanical Engineers Standard:*

Boiler and Pressure Vessel Code, Sections III and XI[4]

2.3 *Nuclear Regulatory Document:*

Code of Federal Regulations, Chapter 10, Part 50, Appendix A – "General Design Criteria for Nuclear Power Plants," Appendix G – "Fracture Toughness Requirements," and Appendix H – Reactor Vessel Material Surveillance Program Requirements"[5]

3. Terminology

3.1 Definitions for terms used in this guide are found in Terminology E170.

4. Significance and Use

4.1 *Regulatory Requirements*—The USA Code of Federal Regulations (10CFR Part 50, Appendix H) requires the implementation of a reactor vessel materials surveillance program for all operating LWRs. Other countries have similar regulations. The purpose of the program is to (*1*) monitor changes in the fracture toughness properties of ferritic materials in the reactor vessel beltline[6] resulting from exposure to neutron irradiation and the thermal environment, and (*2*) make use of the data obtained from surveillance programs to determine the conditions under which the vessel can be operated with adequate margins of safety throughout its service life. Practice E185, derived mechanical property data, and (r, θ, z) physics-dosimetry data (derived from the calculations and reactor cavity and surveillance capsule measurements **(1)** using physics-dosimetry standards) can be used together with information in Guide E900 and Refs. **4, 11-18** to provide a relation between property degradation and neutron exposure, commonly called a "trend curve." To obtain this trend curve at all points in the pressure vessel wall requires that the selected trend curve be used together with the appropriate (r, θ, z) neutron field information derived by use of this guide to accomplish the necessary interpolations and extrapolations in space and time.

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[1] This guide is under the jurisdiction of ASTM Committee E10 on Nuclear Technology and Applications and is the direct responsibility of Subcommittee E10.05 on Nuclear Radiation Metrology.

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[2] The boldface numbers in parentheses refer to the list of references appended to this guide.

[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] Available from American Society of Mechanical Engineers (ASME), ASME International Headquarters, Two Park Ave., New York, NY 10016-5990, http://www.asme.org.

[5] Available from U.S. Government Printing Office Superintendent of Documents, 732 N. Capitol St., NW, Mail Stop: SDE, Washington, DC 20401, http://www.access.gpo.gov.

[6] Per USNRC Regulatory Issue Summary 2014-11 (**10**), the reactor vessel beltline is defined as those portions of the RPV where the accumulated neutron fluence (E > 1.0 MeV) at the end of reactor operation will exceed 10^{17} cm^{-2}. The reactor vessel extended beltline is a term commonly used to refer to materials located outside of the region opposite the active core height that are also expected to accumulate neutron fluence (E > 1.0 MeV) at the end of reactor operation exceeding 10^{17} cm^{-2}.