NEI 16-03, DRAFT BA

Guidance for Monitoring of Fixed Neutron Absorbers in Spent Fuel Pools

AugustMay 2016

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Nuclear Energy Institute

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NOTICE

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FOREWORD

This guidance describes acceptable methods that may be used by industry to monitor fixed neutron absorbers in PWR and BWR spent fuel pools to ensure that aging effects and corrosion and/or other degradation mechanisms are identified and evaluated prior to loss of the intended safety function.

At the request of Nuclear Regulatory Commission staff [14], this document was created as a stand-alone guidance document from Section 9.5 of NEI 12-16, Revision 1, which was submitted to the NRC for endorsement in April 2014. The proposed monitoring program contained herein has been updated based upon discussions with the NRC with input from responses to the Request for Additional Information. Individual vendors or licensees may deviate from the method supplied herein, with appropriate justification and approval by the NRC.

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ABBREVIATIONS AND ACRONYMS

BWR	Boiling Water Reactor
CAP	Corrective Action Program
CFR	Code of Federal Regulations
EPRI	Electric Power Research Institute
ISG	Interim Staff Guidance
LAR	License Amendment Request
LWR	Light Water Reactor
NEI	Nuclear Energy Institute
NRC	Nuclear Regulatory Commission
PWR	Pressurized Water Reactor
QA	Quality Assurance
SFP	Spent Fuel Pool

1 INTRODUCTION

1.1 PURPOSE

This document provides acceptable methods for monitoring of neutron absorbers in spent fuel storage rack at nuclear power plants. This guidance is applicable to both Boiling Water Reactor (BWR) and Pressurized Water Reactor (PWR) spent fuel pools.

This document is developed to provide comprehensive and durable guidance to improve consistency and clarity for implementing neutron absorber monitoring programs. It is envisioned that this guidance will be endorsed by the NRC through a Regulatory Guide, which will achieve durability through NRC concurrence.

1.2 BACKGROUND

Spent fuel storage racks were originally designed to preclude a criticality event through geometric separation and neutronic decoupling of the spent fuel assemblies by a large distance, with no neutron absorbers. However, as reprocessing no longer became a viable option, nuclear plants were faced with storing a greater number of discharged spent fuel assemblies in the spent fuel pool. Since the original racks utilized geometric spacing as the primary method of criticality control, a large part of the spent fuel pool was not efficiently utilized for storage.

Beginning in the late 1970s, industry proposed installing high-density storage racks in the spent fuel pool to accommodate the discharged fuel. Since the fuel assemblies were now placed closer together, other means needed to be employed to preclude a criticality event, namely fixed neutron absorbers installed between each storage cell. Many types of neutron absorbers have been used over the past four decades, but in all cases, the primary neutron absorbing isotope is ^{10}B, which has a large thermal cross-section, and therefore is ideal for absorbing neutrons in the spent fuel pool (i.e., in a system with a strong moderator such as water).

In conjunction with the use of fixed neutron absorbers, the NRC required continual demonstration of the efficacy of the installed neutron absorber, through monitoring of the behavior of the neutron absorber via coupons or in-situ measurements. The frequency of inspections and criteria for inspection was determined on a case-by-case basis, depending upon the type of material, historical operating experience for the specific material to be used, and other factors during the license amendment request process. In some cases, sufficient operating experience was acquired over several decades to allow individual licensees not to need coupons or in-situ examinations, but to rely on the collective industry experience.

With nuclear power reactors, and their associated spent fuel pools, undergoing license renewal for an additional 20 years, the NRC developed guidance of fixed neutron absorbers to support aging management programs for spent fuel pools in NUREG-1801, Revision 2 [10].

1.3 APPLICABLE REGULATIONS

The following regulations are applicable to neutron absorber materials for nuclear fuel storage at LWR facilities:

- Title 10 of the *Code of Federal Regulations* (10 CFR) 50 Appendix A, General Design Criteria for Nuclear Power Plants Criterion 61, "Fuel Storage and Handling and Radioactivity Control." [4]

- Title 10 of the *Code of Federal Regulations* (10 CFR) 50 Appendix A, General Design Criteria for Nuclear Power Plants Criterion 62, "Prevention of Criticality in Fuel Storage and Handling." [3]

- Title 10 of the *Code of Federal Regulations* (10 CFR) 50 Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants." [5]

- Title 10 of the *Code of Federal Regulations* (10 CFR) 50.36, "Technical Specifications." [6]

It is noted that in addition to the applicable regulations, the NRC has developed associated staff review guidance associated with neutron absorbers for nuclear fuel storage at LWR facilities.

- NUREG-0800, Standard Review Plan, Section 9.1.1, "Criticality Safety of Fresh and Spent Fuel Storage and Handling," Revision 4. [8]

- NUREG-0800, Standard Review Plan, Section 9.1.2, "New and Spent Fuel Storage," Revision 3. [9]

- NUREG-1801, Revision 2, "Generic Aging Lesson Learned (GALL) Report," Revision 2, December 2010. [10]

2 NEUTRON ABSORBER MONITORING PROGRAMS[1]

Neutron absorbers serve as an important material to control reactivity in most spent fuel pool storage racks. Neutron absorber monitoring programs should beare developed with the purpose of verifying that the neutron absorbers continue to provide the criticality control relied upon in the criticality analyses. To accomplish this, the monitoring program must be capable of identifying whether changes to the material are occurring, and if those changes are occurring that the anticipated characteristics of change can be verified.

Commented [kwc1]: Conforming change to remove "should". Discussion Point #3

A neutron absorber monitoring program may rely on a combination of the following approaches: 1) Installation of a neutron absorber coupon tree with periodic removal and testing of neutron absorber coupons; 2) In-situ measurements of the neutron absorbing capability of the installed neutron absorber panels, 3) Spent fuel pool water chemistry monitoring. Alternative approaches are also acceptable if adequately justified. A monitoring program should also consists of identifying original material characteristics and testing, awareness of ongoing research and

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[1] While these guidelines for neutron absorber monitoring programs are intended for initial license applications and license amendment requests that install new neutron absorber materials, they may be useful for licensee's consideration in license renewal applications under 10 CFR Part 54.

development, participation in industry groups that share operating experience amongst plants, and evaluation of the relevance of outside data on the in-service material. Acceptance criteria ~~should be developed as~~provide the basis for the comparison of results in order to determine whether material performance is acceptable or actions are necessary to address performance issues.

Commented [kwc3]: Conforming change to remove "should" – Discussion Point #3

2.1 COUPON TESTING PROGRAM

Use of coupons is the preferred method for a neutron absorber monitoring program. The coupon testing program consists of a population of small sections of the same neutron absorber installed in the storage racks. These coupons can either be encased in the same material as the storage rack structure, to simulate the geometry of the storage rack, or they may remain fully exposed to the spent fuel pool environment. The coupons are generally attached to a structure that can be placed in a spent fuel rack storage cell, referred to as a "coupon tree". The coupon tree is placed in a location in the spent fuel pool, near freshly discharged fuel assemblies, to generate an accelerated rate of accumulated exposure to those parameters that may impact aging/degradation mechanisms.

A coupon testing program ~~should meet~~ consists of the following elements~~criteria~~:

Commented [kwc4]: Discussion Point #3a

- The number of coupons needs to be sufficient to provide sampling at an appropriate interval for the intended life of the neutron absorber. The intended life of the neutron absorber ~~should be~~is based upon the amount of time the neutron absorber will be relied upon to provide criticality control. This is typically the life of the plant (including license renewal) plus some additional time to permit off-loading the spent fuel pool during decommissioning.

Commented [kwc5]: Conforming Change to remove "should". Discussion Point #3

- Sampling intervals ~~should be~~are based upon the expected rate of material changes, which may be influenced by the qualification testing of the material. For new materials that do not have applicable operating experience in conditions similar to the pool environment (i.e. their ability to perform over time is not well known), the initial interval ~~for the first inspection should not exceed~~ of 5 years, with subsequent intervals up to 10 years is acceptable. For materials that have been used for several years in conditions similar to the pool environment (i.e. their ability to perform is well known), and for which stability of the material condition has been documented, initial and subsequent intervals up to 10 years is acceptable.

Commented [kwc6]: Conforming change to remove "should" Discussion Point #3

Commented [kwc7]: Conforming change to remove "should". Discussion Point #3

- Coupon testing is categorized as a combination of basic and full testing. The coupon testing is used to identify whether unanticipated changes are occurring. If they are, the condition of the neutron absorber material is determined to evaluate further actions. The extent to which each of these is utilized are determined based upon the operating history of the material, as follows:

  a) Basic testing consists of visual observations, dimensional measurements, and weight that may be performed at the spent fuel pool. These parameters focus on identification of whether changes are occurring in the materials. Basic testing is appropriate when previous testing and operating experience of the material indicates that there are no degradation mechanisms that would result in loss of ^{10}B areal density that would affect reactivity. Basic testing will occur at least every 10 years.

b) Full testing may consist of a combination of mass-density measurements, ^{10}B areal density measurements, microscopic analysis, and characterization of changes, in addition to the basic testing parameters. These parameters focus on quantifying changes if they are occurring in the materials. Full testing should beis performed for the first coupon test, but may not be necessary for subsequent test periods unless a loss of ^{10}B areal density is anticipated based on known operating experience. Basic testing may be used in combination with full testing for materials that have degradation resulting in loss of ^{10}B areal density to extend the interval of full testing, if appropriately justified. The ^{10}B areal density measurement will occur at least every ten years.* . For materials with known degradation or degradation mechanisms that impact the efficacy of the neutron absorber (e.g., Boraflex, Carborundum, Tetrabor or other phenolic resin based materials), the measurement of the areal density at least once every 5 years is acceptable.

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Commented [kwc9]: Discussion Point #1

*Note: For those licensees that are nearing exhaustion of the originally installed coupons in the spent fuel pool, and have a compelling need to extend the life of the neutron absorber coupon monitoring program, an option exists to forego the areal density measurements on the ten year minimum basis. This option would be explored on a site-specific basis, subject to NRC review and approval, supported by the data from the previous neutron absorber coupon measurements that the neutron absorber will continue to serve its intended safety function and that any precursors to degradation will be captured by basic testing. Additionally, this option may warrant more frequent basic testing, depending upon the experience obtained from previous coupon measurements.

Commented [kwc10]: Discussion Point #1

- Coupons should be locatedThe location of the coupons is such that their exposure to parameters controlling change mechanisms (e.g., gamma fluence, temperature) is conservative or similar to the in-service neutron absorbers.

Commented [kwc11]: Discussion Point #3c

- Results are acceptable to confirm the continued performance of neutron absorber materials if either:

  a) For materials that are not anticipated to have a loss of ^{10}B areal density; the ^{10}B areal density of the test coupon is the same as its original ^{10}B areal density (within the uncertainty of the measurement).

  b) For materials that are anticipated to have a loss of ^{10}B areal density; the ^{10}B areal density of the test coupon is greater than the ^{10}B areal density used in the criticality analysis.

2.2 IN-SITU MEASUREMENT PROGRAM

In-situ measurement is another acceptable method for confirming ^{10}B areal density of neutron absorber material. In-situ measurement is used to identify whether changes are occurring, and if they are, to determine the condition of the neutron absorber material. There are two potential uses for in-situ measurements:

1. Supplement coupon monitoring to extend the coupon testing interval or permit greater reliance on basic testing.

2. In lieu of coupon testing if coupons do not exist (i.e., coupons never existed or coupons have been exhausted from periodic coupon testing).

~~Both uses of t~~The in-situ measurement program consists of~~should meet~~ the following ~~criteria~~elements:

Commented [kwc12]: Discussion Point #3b

- In-situ measurement campaigns ~~should be performed on~~include an adequate number of panels and at an acceptable interval. Two options are available for determining an adequate number of panels:

Commented [kwc13]: Discussion Point #3d

  - Option 1: Take a measurement of a minimum of 59 panels, based on the methodology of NUREG-6698 to provide a 95% degree of confidence that 95% of the population is above the smallest observed value.

  - Option 2: Selectively choose panels to be tested that have experienced the greatest exposure (within the top 5%) to those parameters that influence degradation (i.e., radiation fluence, temperature, time). The number of panels selected ~~should be~~ consist of no less than 1% of the total number of panels in the spent fuel pool. Additional panels can be selected from other areas of the spent fuel pool to gain a more representative sampling of the spent fuel pool.

Commented [kwc14]: Conforming change to remove "should" – Discussion Point #3

- It is recommended that i~~I~~n-situ measurement campaigns ~~should~~ consider the availability of equipment to reach storage locations, minimization of spent fuel transfers and separation of the measured storage cells from other spent fuel to minimize signal noise and eliminate corruption of the results by background radiation.

Commented [kwc15]: Conforming change to remove "should" – Discussion Point #3

- The sampling interval is based upon the expected rate of material change, which may be influenced based upon the qualification testing of the material. For new materials that do not have a lot of operating experience in conditions similar to the pool environment (i.e. their ability to perform is not well known), the initial interval ~~should not exceed~~of 5 years, with subsequent intervals up to 10 years is acceptable. For materials that have been used for several years in conditions similar to the pool environment (i.e., their ability to perform is well known), and for which stability in the material condition has been documented, initial and subsequent intervals up to 10 years is acceptable. For materials with known degradation or degradation mechanisms that impact the efficacy of the neutron absorber (e.g., Boraflex, Carborundum, Tetrabor or other phenolic resin based materials), a testing interval of 5 years is acceptable.

Commented [kwc16]: Conforming change to remove "should". Discussion Point #3

Commented [kwc17]: Discussion Point #1

- Note that the sampling interval can be longer if used in conjunction with coupons.

- Sources of measurement uncertainty ~~should~~ are to be identified and the degree of uncertainty quantified.

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Additional criteria for in-situ measurements depend upon the performance of the neutron absorber material, specifically whether material changes result in a degradation of the ^{10}B areal density.

A. For materials where operating experience indicates that potential change mechanisms do not result in a loss of ^{10}B areal density, in-situ measurements are used to confirm their presence and provide validation of the original as-manufactured areal density. Results confirm the continued performance of neutron absorber materials if the nominal measured ^{10}B areal density is equal to or greater than the ^{10}B areal density assumed in the criticality analysis, within the uncertainties of the measurement.

B. For materials where operating experience indicates that degradation mechanisms may result in a loss of ^{10}B areal density, in-situ measurements are used to determine the amount of ^{10}B areal density remaining. Results confirm that potential loss of ^{10}B has not resulted in the loss of the neutron absorber material's ability to perform its criticality control function if the nominal measured ^{10}B areal density minus the measurement uncertainty is greater than the ^{10}B areal density assumed in the criticality analysis.

2.3 Evaluating Neutron Absorber Test Results

Results from neutron absorber monitoring fall within the broad categories of 1) confirmation that no material changes are occurring; 2) confirmation that anticipated changes are occurring; and/or 3) identification that unanticipated changes are occurring. Relevant Pprocesses should be established are used to evaluate results of the monitoring program with the criticality analysis input. If no changes, or if anticipated changes are occurring that have already been accounted for, then the material condition continues to be adequately represented in the criticality analysis.

Commented [kwc19]: Conforming change to remove "should" – Discussion Point #3

If unanticipated changes are identified (either new mechanisms or anticipated mechanisms at rates or levels beyond those anticipated), then additional actions may be necessary. In addition to relevant regulatory and licensing processes (e.g., corrective action program, reporting requirements, the 10 CFR 50.59 [7] process, operability determination or functionality assessment), the following technical evaluations may be necessary:

- Determine if unanticipated changes could result in a loss of ^{10}B areal density. Evaluation of the effects of ^{10}B areal density on the criticality analysis should are to be performed and addressed through appropriate licensee processes.

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- Determine if unanticipated changes not resulting in loss of ^{10}B areal density have an impact on the criticality analyses. Dimensional or non-neutron absorbing material changes (e.g. formation of gaps, localized displacement of moderator, or superficial scratches) may have no or little impact on the criticality analyses. However, the potential effects of these changes on the criticality analysis should, nevertheless, beare evaluated and addressed through appropriate licensee processes.

Commented [kwc21]: Conforming change to remove "should" – Discussion Point #3

3 REFERENCES

3.1 REGULATIONS

1. Title 10 of the *Code of Federal Regulations* (10 CFR) 50.68, Criticality Accident Requirements.

2. Title 10 of the *Code of Federal Regulations* (10 CFR) 70.24, Criticality Accident Requirements.

3. Title 10 of the *Code of Federal Regulations* (10 CFR) 50 Appendix A, General Design Criteria for Nuclear Power Plants Criterion 62, Prevention of Criticality in Fuel Storage and Handling.

4. Title 10 of the *Code of Federal Regulations* (10 CFR) 50 Appendix A, General Design Criteria for Nuclear Power Plants Criterion 61, Fuel Storage and Handling and Radioactivity Control.

5. Title 10 of the *Code of Federal Regulations* (10 CFR) 50 Appendix B, Quality Assurance for Nuclear Power Plants and Fuel Reprocessing Plants.

6. Title 10 of the *Code of Federal Regulations* (10 CFR) 50.36, Technical Specifications.

7. Title 10 of the *Code of Federal Regulations* (10 CFR) 50.59, Changes, Tests and Experiments.

3.2 NUREGs

8. NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition," Section 9.1.1, "Criticality Safety of Fresh and Spent Fuel Storage and Handling," Revision 3, March 2007.

9. NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition," Section 9.1.2, "New and Spent Fuel Storage," Revision 4, March 2007.

10. NUREG-1801, "Generic Aging Lessons Learned (GALL) Report," Revision 2, December 2010

3.3 OTHER

11. NRC Memorandum from L. Kopp to T. Collins, Guidance on the Regulatory Requirements for Criticality Analysis of Fuel Storage at Light-Water Reactor Power Plants," August 19, 1998.

12. "Handbook of Neutron Absorber Materials for Spent Nuclear Fuel Transportation and Storage Applications," EPRI, Palo Alto, CA: 2009. 1019110.

13. "Strategy for Managing the Long-Term Use of Boral® in Spent Fuel Storage Pools," EPRI, Palo Alto, CA: 2012. 1025204.

14. "Summary of October 21, 2015, Public Meeting with Nuclear Energy Institute on NEI 12-16, Revision 1, 'Guidance for Performing Criticality Analysis of Fuel Storage at Light-Water Reactor Power Plants'", ML15294A491