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	Supporting Divisions:	NRR/DCI
		NRR/DIRS
		NRR/DORL
		NRR/DLR
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	Supporting Offices:	NRO
		NMSS
		RES
	External Stakeholders:	NEI

GOAL

"The mission of the U.S Nuclear Regulatory Commission is to license and regulate the Nation's civilian use of byproduct, source, and special nuclear materials in order to protect public health and safety, promote the common defense and security, and protect the environment." This is reemphasized as a "Strategic Goal" where the safety goal is to "Ensure adequate protection of public health and safety and the environment," with an expected strategic outcome to "Prevent the occurrence of any inadvertent criticality events." The goal of this Action Plan is to focus on the prevention of an inadvertent criticality event in the spent fuel pool.

DESCRIPTION

The conservatism/margin in spent fuel pool (SFP) criticality analyses has been decreasing. This is due to a confluence of factors. Lack of a federal repository for spent nuclear fuel (SNF) has required licensees to modify existing SFP storage rack designs to increase SNF storage capacity. In some cases, storage racks were placed into open areas of the SFP, but the dimensions of the SFPs cannot be changed so licensees are putting more fuel assemblies into the same volume. Fuel assemblies themselves have become more reactive. Increased U235 enrichment is an obvious example. But there are other more subtle changes: increased fuel pellet diameter, increased fuel pellet density, the boiling water reactor (BWR) transition from fuel assemblies with 49 fuel rods to those with 91 fuel rods, increased use of fixed and integral burnable absorbers, and even changes to core operating parameters due to power uprates result in more reactive fuel assemblies to be stored in the SFP. The new rack designs rely heavily on permanently installed neutron absorbers to maintain criticality requirements. Unfortunately, virtually every permanently installed neutron absorber, for which a history can be established, has exhibited some degradation. Some have lost a significant portion of their neutron absorbing capability. In some cases, the degradation is so extensive that the permanently installed neutron absorber can no longer be credited in the criticality analysis. To accommodate these factors both the SFP criticality analyses and the storage requirements have become more complex.

Recent license amendment requests (LAR) have not always included sufficient critical examination of assumptions to address the increased complexity of the new SFP criticality environment. NRC review of previous assumptions has led the staff to question several of these prior assumptions including some contained in staff guidance.

BACKGROUND

The original storage racks had relatively large center-to-center spacing between the storage cells. The space between the storage cells provided extreme over-moderation and the racks were generally referred to as a 'flux trap' design. An early step to increase SFP capacity was to place new storage racks in areas of the SFP originally intended to remain empty. These new racks generally had smaller center-to-center spacing for the storage cells, and hence the fuel assemblies, which, in some cases, completely eliminated the 'flux trap.' The smaller pitch allowed more fuel assemblies to be stored in a smaller area. These higher density storage racks include a permanently installed neutron absorber to accommodate the closer proximity of the fuel assemblies to each other. Another step was to replace the original storage racks with high-density storage racks. One plant went through several steps to go from a SFP originally licensed for a capacity of 600 fuel assemblies to its current licensed capacity of 3300. Other plants are also increasing SFP capacity. Today a plant may have significantly increased SFP capacity and have several different SFP rack designs within its SFP.

BWR SFP storage controls are typically based on a limiting fuel assembly lattice. BWR fuel assemblies have axial variations in U235 enrichment, integrated neutron absorbers, and even the number of fuel rods. These variations define the different lattices within a BWR fuel assembly. Today's BWR lattices contain significant amount of the neutron absorber gadolinium. Because of the gadolinium, BWR fuel assemblies are more reactive after the gadolinium has been 'burned' out during irradiation in an operating reactor. Therefore, an in-reactor depletion analysis is required to find the most reactive point in the life of a BWR fuel assembly lattice. A given BWR storage rack will be able to accommodate a corresponding limiting fuel assembly. With a fully intact neutron absorber, the limiting fuel assembly can be fairly reactive, usually much more reactive than what the licensee typically uses. The licensee would typically set the technical specification (TS) limit on the reactivity of limiting lattice the storage rack could accommodate and was free to alter fuel and gadolinium loadings so long as the TS limit was not exceeded.

Pressurized water reactors (PWR) SFP storage controls are typically based on a combination of initial U235 enrichment and burnup. A PWR SFP would typically end up with high density and "moderate density" racks. For PWR high density racks, the licensee, in addition to taking credit for the permanently installed neutron absorber, also typically took some burnup credit. Burnup credit accounts for the net reduction of fissile isotopes and the net build up of neutron absorbers as the fuel assembly is irradiated in an operating reactor. Therefore, an in-reactor depletion analysis is required to find the reactivity at various amounts of burnup. The amount of burnup required to meet the criticality requirement would vary with enrichment. This pairing of burnup and enrichment to meet requirements lead to the formation of burnup/enrichment loading curves that would prescribe how much burnup was required for a given enrichment. PWRs have a need to store fresh fuel assemblies in the SFP. To accommodate that need PWRs typically installed "moderate density" storage racks with smaller flux traps than the original and usually more neutron absorber than the high-density storage racks. With a fully intact neutron absorber, burnup requirements for the high-density storage racks can be fairly low and fresh fuel up to 5.00 w/o U235 could easily be accommodated in the moderate density storage racks.

Virtually every permanently installed neutron absorber, for which a history can be established, has degraded in the SFP environment. BORAFLEX™ was used in many of the early SFP re-rack campaigns. It exhibited degradation soon after installation. The recent identification of the neutron absorber Carborundum's™ extensive degradation in the SFP racks at Palisades rivals that of BORAFLEX™ and is particularly troubling to the staff because there was no monitoring program. Another popular material is BORAL™. BORAL™ has been shown to develop blisters and bulges. Currently, the blisters have been small and considered to be cosmetic, however there has been evidence of these blisters increasing in size and in number. The mechanism and effect of the growth is unknown. In addition, there has been no long-term evidence that the blisters will remain cosmetic over the life of a SFP storage rack. In addition, there are new materials coming into play, such as METAMIC, but they do not have any significant history by which to judge their longevity.

The fuel assemblies have become more reactive. Increased U235 enrichment is an example. But there are other more subtle changes; e.g.: increased fuel pellet diameter; increased fuel pellet density; the BWR transition from fuel assemblies with 49 fuel rods to those with 91 fuel rods; increased use of fixed and integral burnable absorbers; and, changes to core operating parameters due to power uprates resulting in more reactive fuel assemblies to be stored in the SFP.

The confluence of these factors have caused SFP criticality analysis and storage controls to become more complex, in that SFP LARs are taking credit for items that previously were not part of a SFP criticality analysis. For example, recent license amendment requests have credited various combinations of the following: Pu241 decay, Am241 buildup, axial blankets, integral burnable poisons on fresh fuel assemblies, and increased burnup (as high as 78 GWD/MTU). The proposed storage configurations are becoming more complicated. A recent LAR would have doubled the number of storage configurations from eight to 16 and doubled its number of categorizations of the fuel assemblies from 12 to 24. That LAR was withdrawn after the request for additional information identified significant technical and quality issues; e.g. increasing reactivity with Pu241 decay.

The issues discussed above have resulted in reduced margins to criticality, thus reducing or eliminating the ability to use engineering judgment when determining that there is reasonable assurance that an inadvertent SFP criticality cannot occur. Additionally, uncertainties associated with SFP criticality analyses, due to lack of benchmark data for example, also decrease margins to criticality. This necessitates a more detailed review by the NRC staff and additional Requests for Additional Information to licensees to obtain the necessary data to determine the acceptability of the licensee's SFP criticality analysis.

Additionally, coupling these technical issues with the quality issues of recent submittals (weak or no basis for assumptions, data not benchmarked, incorrect information, missing information, all factors contributing to criticality not identified or adequately quantified, etc.), has increased the review effort significantly. In addition, there has been a significant increase in the number of SFP submittals. Between January 2006 and December 2009 the NRC received 27 SFP LARs, previously the rate had been one or two a year. The rate of submissions is projected to continue at this high level for at least the next several years. This workload has hindered the staff's ability to get ahead of these issues.

To resolve these issues the following activities have occurred or are in progress:

1) Additional staff has been assigned to work on SFP criticality issues.
2) Existing and new NRR/DSS staff has been attending and completing SFP criticality related training and workshops as well as networking with other NRC Offices/Divisions (NRO, NMSS, and NRR/DCI) with related concerns.
    a) University of Tennessee's Nuclear Criticality Safety course.
    b) KENO V.a training.
    c) NMSS sponsored Burnup Credit training seminar.
    d) NMSS Nuclear Criticality Safety Technical Advisory Group.
3) To address the workload issue NRR/DSS/SRXB has put in place contracts with Oak Ridge National Laboratory to perform the technical reviews on an as needed basis.

Improving the NRC guidance to the licensee is the primary goal of this Action Plan. The primary current NRC guidance is an internal 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 (Reference 7). This internal memorandum is known colloquially as the 'Kopp Letter,' after the author. The Kopp Letter is referenced by virtually all SFP criticality LARs submitted since its issuance. A significant portion of the guidance is based on engineering judgment. The technical basis supporting this engineering judgment may need to be updated given the current methodologies employed in SFP criticality analyses so that its scope and intent can be more readily confirmed. Additional guidance consists of an April 14, 1978 NRC, Letter to All Power Reactor Licensees from B. K. Grimes, "*OT Position for Review and Acceptance of Spent Fuel Storage and Handling Applications*" (Reference 8); Standard Review Plan section 9.1.1; Criticality Safety of Fresh and Spent Fuel Storage and Handling (Reference 5), and RegGuide 1.13; Spent Fuel Storage Facility Design, Spent Fuel Facility Design Basis (Reference 16). The rest have been referenced less than a handful of times by licensees.

<u>Problem Statement</u>

The above-indicated factors have resulted in the requirement for increasingly complex analytical methods and administrative controls to determine and maintain SFP sub-criticality. The use of engineering judgment, to the extent it was used in the past, is no longer supportable since margins to criticality have been reduced for reasons discussed above and fuel designs are more complex. Replacing regulatory guidance based on engineering judgment with guidance based on technically substantiated methods will improve regulatory certainty by placing the guidance on a firm footing. Therefore, this Action Plan will:

1) Develop regulatory guidance for the performance and review of SFP criticality analyses to reduce the reliance on engineering judgment without sufficient technical basis.

REGULATORY OUTCOME

<u>SFP Criticality Analysis</u>

Two main areas where engineering judgment have been used have been identified to date: depletion uncertainty and benchmark experiments used to validate the computer code used to determine the SFP reactivity.

The Kopp Letter states, “A reactivity uncertainty due to uncertainty in the fuel depletion calculations should be developed and combined with other calculational uncertainties. In the absence of any other determination of the depletion uncertainty, an uncertainty equal to 5 percent of the reactivity decrement to the burnup of interest is an acceptable assumption.” The basis for this guidance appears to be engineering judgment. The basis for the engineering judgment was never captured. There is disagreement between the NRC staff and industry over the basis, intent, and scope of the guidance. Resolving the technical basis for the depletion portion of the SFP criticality analysis is one goal of this action plan. The NUREG/CR has been issued and will be included in the final guidance document.

The Kopp Letter also states, “The proposed analysis methods and neutron cross-section data should be benchmarked, by the analyst or organization performing the analysis, by comparison with critical experiments. This qualifies both the ability of the analyst and the computer environment. The critical experiments used for benchmarking should include, to the extent possible, configurations having neutronic and geometric characteristics as nearly comparable to those of the proposed storage facility as possible.” However, historically the critical experiments used in the benchmarking do not include Actinide and Fission Product nuclides that are important to determining reactivity in a SFP environment. Rather than address the issue in the validation, SFP LARs were silent on the issue. This is inconsistent with NRC guidance on performing these validations as described in NUREG/CR-6698 (Ref. 10). Historically there were no publicly available experiments with Actinide and Fission Product nuclides. With the issuance of NUREG/CR-6979 (Ref. 13), experiments with Actinides are available for benchmarking. However, there are still limited experiments that contain Fission Products that can be used in the validation. Determining the effect of performing the validation in several scenarios, without Actinides and Fission Products, with Actinide but without Fission Product, and with Actinide and Fission Product nuclides is an additional goal of this Action Plan. The NUREG/CR has been issued and will be included in the final guidance document.

Another area where engineering judgment has been used is in modeling the SNF with the properties and dimensions of fresh fuel. As a fuel assembly is depleted in an operating reactor, it undergoes physical changes. Some of those changes have the potential to affect the SFP criticality analysis. For example, fuel rods experience irradiated rod growth. As the rods get longer, the cladding gets thinner. Thinner cladding usually results in a higher reactivity. As the amount of burnup credited in the analysis increases the more of an effect this could have on the criticality analysis. The Action Plan includes a provision to have the physical effects evaluated and a technical basis for their treatment established. The Action Plan envisions a NUREG/CR or Branch Technical Position paper to establish a technical basis for this item.

To cover the period until the NUREG/CRs are published the Action Plan calls for the issuance of interim staff guidance (ISG) on the staff’s expectations on SFP criticality analyses.

Following the issuance of the NUREG/CRs would be the development of more permanent guidance such as a RegGuide that would incorporate the ISG and any other items that need resolving.

Following the RegGuide, the Standard Review Plan would be updated and the Kopp Letter and the 1978 B. K. Grimes, “*OT Position for Review and Acceptance of Spent Fuel Storage and Handling Applications,*” would be retired.

Neutron Absorber Degradation

The ability of licensees to control the material condition of any permanently installed neutron absorber that is credited for maintaining sub-criticality is essential for the prevention of an inadvertent criticality event (ICE). Recently enforcement actions have been taken against two licensees for their failure to maintain control of the material condition of their permanently installed neutron absorber. NRR/DE has the lead for establishing guidance with respect to the material condition of the neutron absorbers. RES is being requested to assist in determining the state of knowledge with respect to the longevity of permanently installed neutron absorbers, the need for additional information, and recommendations for additional guidance. This Action Plan is being closely coordinated with NRR/DE in this regard and anticipates the issuance of guidance with respect to the material condition of the neutron absorbers concurrent with the aforementioned RegGuide. To date the following regulatory actions have been taken to address the neutron absorbers until final guidance can be issued:

Information Notice 2009-26, "DEGRADATION OF NEUTRON-ABSORBING MATERIALS IN THE SPENT FUEL POOL" has already been issued to alert licensees to recent occurrences of degradation.

NRR/DCI/CSGB will issue a User Need to RES to establish the state of the knowledge concerning SNF permanently installed neutron absorbers, identify areas where more information is needed, and set acceptance criterion for monitoring/testing programs.

ONGOING REGULATORY ACTIVITIES

- Information Notice on Misloading Events – Scheduled for release early 2014
- Information Notice on EPU Effect on Spent Fuel Pool Criticality - Scheduled for release early 2014
- Generic Letter on Neutron Absorbers – Scheduled for public comment Winter 2014
- Technical Specification Review – Ongoing. Final STS scheduled for release Winter 2014
- SRP 9.1.1, Criticality Safety of Fresh and Spent Fuel Storage and Handling – Scheduled for release Fall 2015
    - Incorporate staff's guidance on the criticality analysis
    - Remove any inadvertent endorsement of ANSI/ANS standard.
- SRP 9.1.2, New and Spent Fuel Storage – Scheduled for release Fall 2015
    - Incorporate staff's guidance on the neutron absorbers
    - Remove any inadvertent endorsement of ANSI/ANS standard.
- Regulatory Guide 1.13, Spent Fuel Storage Facility Design Basis – Scheduled for release Fall 2015
    - Issue revision to incorporate staff's guidance on neutron absorbers
    - Remove any inadvertent endorsement of ANSI/ANS standard.
- ANS 8.27, Burnup Credit for LWR Fuel, participate in Standards Committee. - Ongoing
- Nuclear Criticality Safety (NCS) Technical Advisory Group (TAG), participate in NCS TAG.
    - Ongoing, meetings are held semiannually
- Review of NEI 12-16 Guidance Document – Ongoing, scheduled to be complete 2015
- Review of Westinghouse Guidance Document – Ongoing, scheduled to be complete 2015

- Review of EPRI Depletion Validation Methodology – Ongoing, scheduled to be complete 2015
- Develop an SDP related to SFPs including the degradation of the neutron absorbing materials – TBD

CURRENT STATUS

Industry Engagement Activities

NRR/DSS attended the NEA Working Party on Nuclear Criticality Safety in Paris, France September 17-21, 2012.

NRR/DSS and NRR/DE held a public meeting on neutron absorber degradation at the NRC October 4, 2012.

NRR/DSS and NRR/DE went on a fact finding trip to observe how metal matrix composites (MMC) are manufactured December 3-6, 2012.

NRR/DSS addressed the industry on spent fuel pool issues at the 2013 RIC.

NRR/DSS attended the NEI Used Fuel Conference in St. Petersburg, FL May 7-9, 2013.

NRR/DSS and NRR/DE held its first meeting with industry to discuss the NEI 12-16 guidance document September 24, 2013

NRR/DSS attended the NCSD Topical Meeting in Wilmington, NC September 29- October 3, 2013.

NRR/DSS and NRR/DE held its second meeting with industry to discuss the NEI 12-16 guidance document October 31, 2013

NRR/DE will address the industry on neutron absorber issues at the 2014 RIC.

NRR/DE will attend the NEI Used Fuel Conference, May 6-10, 2014.

NRC Coordination Activities

NRR/DSS and NMSS/DSFST have personnel on the American Nuclear Society's 8.27, Burnup Credit for LWR Fuel, standard committee.

NRR/DSS/SRXB, NRR/DCI/CSGB, and NRO/DSRA personnel are participating in the NRC Nuclear Criticality Safety Technical Advisory Group.

NRR/DSS, NMSS/DSFST, and NRO/DSRA are cooperating on having ORNL establish technical bases for the depletion uncertainty and code validation issue, with RES as the contracting office. This work will address two of the primary goals of the Action Plan.

NRR/DSS and NRO/DSRA are represented on the COMDEK 09 001, Revisiting the Paradigm for Spent Fuel Storage and Transportation Regulatory Programs, working group. NMSS/DSFST has the lead.

NRC Regulatory Actions

NRR/DSS is evaluating path forward.

NRR/DSS is encouraging potential SFP applicants to come in for face to face meeting to discuss lessons learned from previous LARs and current expectations.

NRR/DE has issued IN 2009 26, "DEGRADATION OF NEUTRON-ABSORBING MATERIALS IN THE SPENT FUEL POOL."

NRR/DLR has published Revision 2 of NUREG 1801 Generic Aging Lessons Learned (GALL) Report in December 2010, which incorporates staff guidance regarding plant specific aging management review for neutron absorbers.

NRR/DE is currently maintaining a User Need to RES to establish the state of the knowledge concerning SNF permanently installed neutron absorbers, identify areas where more information is needed, and set acceptance criterion for monitoring/testing programs.

NRR/DSS has issued Final ISG "DSS-ISG-2010-1: STAFF GUIDANCE REGARDING THE NUCLEAR CRITICALITY SAFETY ANALYSIS ACCOMPANYING SPENT FUEL POOL LICENCE AMENDMENT REQUESTS."

NRR/DSS has issued Information Notice 2011-03: "USE OF RACKLIFE AND BADGER MONITORING PROGRAMS IN EVALUATION OF BORAFLEX DEGRADATION IN SPENT FUEL POOLS."

NRR/DSS has issued NUREG/CR-7108: "An Approach for Validating Actinide and Fission Product Burnup Credit Criticality Safety Analyses-Isotopic Composition Predictions."

NRR/DSS has issued NUREG/CR-7109: "An Approach for Validating Actinide and Fission Product Burnup Credit Criticality Safety Analyses-Criticality (Keff) Predictions."

NRR/DE has issued Information Notice 2012-13: "BORAFLEX DEGRADATION SURVEILLANCE PROGRAMS AND CORRECTIVE ACTIONS IN THE SPENT FUEL POOL."

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REFERENCES

1. 10 CFR 50.36, Technical Specifications
2. 10 CFR 50.68, Criticality Accident Requirements
3. 10 CFR 50 Appendix A, General Design Criteria for Nuclear Power Plants
4. 10 CFR 70.24, Criticality Accident Requirements
5. SRP 9.1.1, Criticality Safety of Fresh and Spent Fuel Storage and Handling
6. SRP 9.1.2, New and Spent Fuel Storage
7. 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. (ADAMS ML003728001)
8. B. K. Grimes, "*OT Position for Review and Acceptance of Spent Fuel Storage and Handling Applications;*"
9. NUREG/CR-6665, Review and Prioritization of Technical Issues Related to Burnup Credit for LWR Fuel.
10. NUREG/CR-6698, Guide for Validation of Nuclear Criticality Safety Calculational Methodology.
11. NUREG/CR-6801, Recommendations for Addressing Axial Burnup in PWR Burnup Credit Analysis
12. NUREG/CR-6811, Strategies for Application of Isotopic Uncertainties in Burnup Credit
13. NUREG/CR-6979, Evaluation of the French Haut Taux de Combustion (HTC) Critical Experiment Data
14. EPRI TR-1013721, Handbook of Neutron Absorber Materials for Spent Nuclear Fuel Transportation and Storage Applications
15. Information Notice 2009-26, Degradation of Neutron Absorbing Materials in the Spent Fuel Pool.
16. RegGuide 1.13, Spent Fuel Storage Facility Design Basis
17. RIS 2001-012, Nonconservatism in Pressurized Water Reactor Spent Fuel Storage Pool Reactivity Equivalencing Calculations
18. RIS 2005-005, Regulatory Issues Regarding Criticality Analyses for Spent Fuel Pools and Independent Spent Fuel Storage Installations
19. LIC-502, Procedure for Development, Implementation, and Management of Action Plans
20. DSS-ISG-2010-1, Staff Guidance Regarding the Nuclear Criticality Safety Analysis Accompanying Spent Fuel Pool License Amendment Requests
21. Information Notice 2011-03, Use of RACKLIFE and BADGER Monitoring Programs in Evaluation of BORAFLEX Degradation in Spent Fuel Pools

Communication Plan

Key messages

The Action Plan will establish new and updated NRC guidance for SNF criticality analyses that is consistent with the current criticality environment.

Background

As contained in the main body of the action plan.

Audience/Stakeholders

As contained in the main body of the action plan.

Communication Team

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Communication Tools

NRC Public Meetings
Attendance at industry conferences
Interim Staff Guidance
Regulatory Issue Summary
NUREG/CR
Regulatory Guides
Standard Review Plan
Email
Direct Mail

Timeline
See Milestones section in the Action

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